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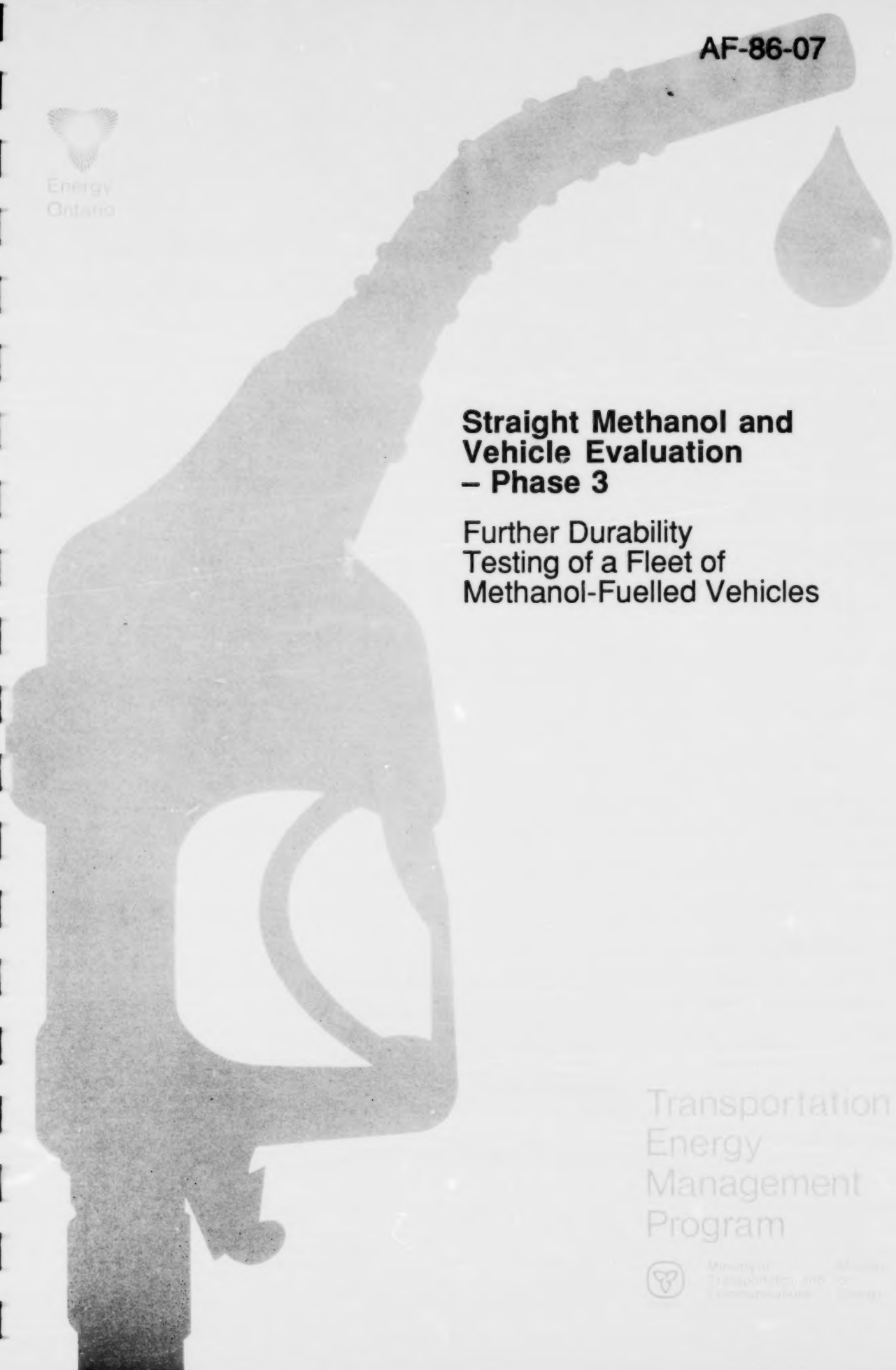

Straight Methanol and Vehicle Evaluation – Phase 3

Further Durability Testing of a Fleet of Methanol-Fuelled Vehicles

Transportation Energy Management Program

AF-86-07

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Further Durability Testing of a Fleet of Methanol-Fuelled Vehicles

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Abstract:
Six methanol-fuelled vehicles have been operated over a severe multiple short-trip mode of distance accumulation. Pairs of vehicles were run for the duration of the test, with three different engine oil formulations designed to control engine wear. The vehicle engines were stripped and measured at the beginning and end of the period so that direct assessment of wear could be made. This was supplemented with regular sampling and analysis of the oil to check for trace wear metals and deterioration of lubricant quality. A range of methanol fuel compositions containing from 78 to 90% methanol was used over the period, and the volatility was seasonally adjusted with the addition of gasoline as well as, in some cases, dimethyl ether.

Key Words: methanol vehicle, engine wear, methanol engine oils

Comments:

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EXECUTIVE SUMMARY

Six Ford Escorts modified by the manufacturer for near-neat methanol fuel, commonly called "fuel methanol," have been used in short-trip operation for approximately nine months by Shell Canada.

Pairs of vehicles were run for the duration of the test, with three different engine oil formulations designed to control engine wear. The vehicle engines were stripped and measured at the beginning and end of the period so that direct assessment of wear could be made. This was supplemented with regular sampling and analysis of the oil to check for trace wear metals and deterioration of lubricant quality. A range of methanol fuel compositions containing from 78 to 90% methanol was used over the period, and the volatility was seasonally adjusted with the addition of gasoline, as well as, in some cases, dimethyl ether.

The specially designed oils performed acceptably in the short-trip cold-engine driving test, with low sludge, varnish, and valve deposits. However, engine measurements and used-oil analysis indicated wear in rings and cams. Energy consumption was approximately equal to that of equivalent gasoline-powered cars during summer ambient conditions over the road and when tested on the chassis dynamometer. Energy consumption during winter months was about 25% greater. Cold weather performance -- startability and driveability -- is still poorer than would be expected with an equivalent gasoline vehicle. However, improvements were obtained over previous experience as the result of some hardware changes and the use of fuels of greater volatility.

The results of this program indicate that

- further development of the vehicle is required to ensure acceptable cold weather operation;
- further testing is required to ensure that the engine and its oil will allow sufficient engine durability compared to conventionally fuelled engines; and
- most, if not all, of the material compatibility problems can be solved with "fuel-methanol."

1/ INTRODUCTION

Fuel-methanol, or near-neat methanol fuel, is considered to be a possible further alternative to conventional hydrocarbon (HC) fuels. For approximately two years, Shell Canada, in association with Ford of Canada, has operated a small fleet of 1983 Ford Escorts, which were built to operate on fuel-methanol.

This program, now in its third phase, has been partially financed by both the provincial and federal governments under the Transportation Energy Management Program (TEMP), administered by the Ontario Ministry of Transportation and Communications and Ministry of Energy.

Phase 1 of this program addressed problems with cold weather operation of these methanol-fuelled Ford Escorts [1]. Phase 2 concerned the durability of these vehicles via a longer term fleet test under Canadian climatic conditions [2]. Phase 3, as detailed in this report, concerns a test of six of these cars under short-trip driving conditions.

2/ TEST METHODS

2.1/ Test Cars

The vehicles in the test fleet were 1983 Ford Escorts developed by the Ford Motor Company to operate on fuel-methanol. Originally, this fuel was specified as a blend of 90% by volume methanol (MeOH) and 10% by volume winter-grade non-leaded gasoline. Then Ford Motor Company changed the specification to 85% by volume methanol and 15% by volume high aromatic (greater than 40% by volume) winter-grade non-leaded gasoline, during the time period of this phase.

Test car specifications are given in Table 1. Six vehicles, which were originally part of the test fleet used in Phase 2 of this program, were operated at Shell Canada (Appendix A).

The cars were calibrated to meet the 1983 California emission standards. The maximum emission levels under this standard are 0.24 g HC/km (0.39 g HC/mi) (non-methane standard), 4.3 g carbon monoxide (CO)/km (7.0 g CO/mi), and 0.43 g oxides of nitrogen (NO_x)/km (0.7 g NO_x/mi).

2.2/ Test Fuels

The test fuel used, fuel-methanol or near-neat methanol, varied during the test period. Table 2 lists the inspection properties of the six fuel blends used in the test, from November 1984 until August 1985. Table 3 details the properties of the fuel blend components. The fuel blends varied mainly in energy content and volatility.

The test fuel was stored and dispensed from a 4546 L (1000 imp. gal) stainless steel, above-ground, storage tank on site.

2.3/ Test Oils

The major concern in Phase 3 was to evaluate engine durability under short-trip (commonly called "Aunt Minnie") driving conditions. Three different oils were blended for use in the six-car test fleet.

Table 4 details the inspection properties of the three oils, which were blended using Shell Canada and synthetic base stocks and three different additive packages:

Table 1/ Test Vehicle Specifications

Model	1983 Ford Escort
Body Styles	4-door hatchback, station wagon
Engine Type	OHC, in-line 4 cylinder
Bore x Stroke, mm	80 x 79
Capacity, L	1.6
Compression Ratio	11.8 : 1
Power Output	85 hp at 5200 rpm
Top Ring Type	Barrel faced, chrome plated
Head Gasket	1984 type - stainless steel fire rings
Camshaft Type	Base
Distributor	Modified spark curve (vs. gasoline version)
Spark Plug Type	AGSF12C
Fuel System Specifications	- Stainless steel fuel tank - Stainless steel fuel lines - Nickel-plated in-tank sending unit - Nylon-coated fuel tank straps - Nickel-plated fuel pump - Nickel-plated, recalibrated carburetor - New carburetor spacer with electrical heating unit

Table 2/ Test Fuel Blend Inspection Properties

	Blend 7		Blend 8		Blend 9		Blend 10		Blend 11		Blend 12	
COMPONENTS	% by Vol.	% by Mass	% by Vol.	% by Mass	% by Vol.	% by Mass	% by Vol.	% by Mass	% by Vol.	% by Mass	% by Vol.	% by Mass
Methanol (MeOH)	90.0	90.6	85.3	86.1	77.7	79.4	84.4	85.4	85.0	85.9	85.0	85.9
Super Non-Leaded Gasoline (SNL)	10.0	9.4	14.7	13.9	14.7	14.2	15.0	14.1	15.0	14.1	15.0	14.1
Dimethylether (DME)	-	-	-	-	7.6	6.4	0.6	0.5	-	-	-	-
Carbon		41.9		44.5		45.4		44.5		44.4		44.4
Hydrogen		12.7		12.6		12.7		12.6		12.6		12.6
Oxygen		45.4		42.9		41.9		42.9		43.0		43.0
TIME PERIOD	Sept.20/84 to Dec.6/84		Dec.7/84 to Jan.9/85		Jan.10/85 to Feb.20/85		Feb.21/85 to May 15/85		May 16/85 to July 26/85		July 27/85 to Sept. 1/85	
INSPECTION PROPERTIES												
Density, kg/L	0.793		0.791		0.780		0.786		0.789		0.789	
ASTM D-86 Distillation:												
IBP, °C	52		50		31		59		49		59	
10%, °C	62		63		45		61		62		61	
50%, °C	64		64		64		64		64		64	
90%, °C	64		64		65		64		65		64	
EP, °C	67		66		169		66		65		66	
% Recovery	97.6		98.9		94.1		98.0		98.8		98.1	
RVP (Dry), kPa (psi)	49.2(7.1)		49.6(7.2)		122(17.7)		65.2(9.5)		56(8.1)		53.1(7.7)	
Water Content, mg/kg	-		356		332		132		273		549	
Chloride Content, mg/kg	-		<1.0		2.5		1.8		<1.0		<1.0	
Calculated Energy Content MJ/kg	22.1		23.2		23.8		23.3		23.2		23.2	
(Net or LH Value) MJ/L	17.5		18.3		18.5		18.4		18.3		18.3	
Energy Content Blend 7 / Energy Content Blend N	1.000		0.956		0.946		0.951		0.956		0.956	

Table 3/ Base Component Inspection Properties

COMPONENTS	SNL (Blends 7,8)	SNL (Blends 9,10)	SNL (Blends 11,12)	DME	MeOH (Typ.)
INSPECTION PROPERTIES					
Density, kg/L	0.750	0.742	0.748	0.661	0.797
ASTM D-86 Distillation:					
IBP, °C	29	27	32	-25	64
10%, °C	47	40	52	-	64
50%, °C	101	106	109	-	64
90%, °C	156	155	153	-	64
EP, °C	198	195	204	-25	67
% Recovery	98.4	93.2	96.8	-	99.8
C, % by Mass	86.7	86.6		52.1	37.5
H, % by Mass	13.3	13.4		13.0	12.5
O, % by Mass	-	-		34.9	50.0
RVP (Dry), kPa (psi)	68.0 (9.9)	94.2 (13.7)	69.0 (10.0)	850 (123)	30.2 (4.4)
Water Content, mg/kg	-	125	-	-	425
Cl, mg/kg	-	<1.0	-	-	<1.0
Energy Content MJ/kg (Book Value)	43.5	43.5	43.5	28.9	19.9
(Net or LH Value) MJ/L	32.2	32.2	32.2	19.1	15.9

Table 4/ Test Oil Inspection Properties

Oil Type	Oil A	Oil B	Oil C	Original Oil
Oil Code	AL41036	AL41059	AL50223	
SAE Viscosity Grade	10W20	10W30	10W20	10W20
COMPONENTS				
Base Oil	x	x	x	x
Synthetic Oil	x		x	x
Additive Package	x	x	x	x
INSPECTION PROPERTIES				
Viscosity at 40°C, cSt	56.3	68.1	51.4	52.4
Viscosity at 100°C, cSt	8.7	10.7	7.8	8.3
CCS Viscosity at -20°C, cP	3100.0	2850.0	3400.0	2750.0
Pour Pt., °C	-48	-45	-18	-42
Density, kg/L	0.888	0.883	0.885	0.890
Sulphated Ash, % by Mass	1.59	1.51	1.56	2.88
Mg, mg/kg	<1.0	7.1	2378	24
Zn, % by Mass	0.18	0.15	0.16	0.19
Ca, % by Mass	0.35	0.34	0.10	0.77
TANe, D-664, mgKOH/g	2.0	2.7	2.5	2.4
TBNe, D-664, mgKOH/g	14.0	6.2	12.9	12.4
TBNe, D-2896, mgKOH/g	14.8	10.3	14.2	16.6

1/ one developed by Shell Canada at the Oakville Research Centre (ORC);
2/ one developed by Paramins, a division of Exxon, as a replacement for its original package, used by the Ford Motor Company in their methanol factory-fill oil; and
3/ one developed by the Lubrizol corporation for use in light-duty methanol-fuelled engines.

These additive packages were developed specifically for fuel-methanol engines because earlier testing by various researchers indicated that normal gasoline engine lubricants would not give acceptable engine durability [3-7]. Engine wear with methanol fuel was greater than with gasoline at lower oil temperatures (i.e., less than 70°C) and was mainly in the upper cylinder bores and piston rings, with some wear of the cam lobes, followers, and bearings. Rusting of the cylinder bores and crankshaft journals also occurred. In some studies [7], increased intake system deposits occurred, because the viscosity index improver in the oil degraded upon contact with methanol.

The wear associated with the use of fuel-methanol appears to have the following mechanism: incompletely vaporized methanol condenses on the cylinder walls and, because of its polar nature, penetrates or removes the oil film. During combustion, various intermediate compounds, including gaseous formaldehyde, peroxides, and water, are formed. These compounds diffuse to the methanol film now on the cylinder wall and are dissolved in it. Formic acid is formed and reacts with the iron to form iron formate, which then decomposes to iron oxide and is removed by the passage of the piston rings up and down the cylinder bore. These abrasive particles can then find their way to other areas of the engine and cause increased wear.

The rusting of engine components is most likely caused by emulsions of fuel-methanol, water, and engine oil, which occur during cold operation and collect on the metal surfaces. This, again, is primarily due to the chemically reactive, polar nature of methanol.

To combat these problems, the three additive packages were developed. Because all three are proprietary to the suppliers involved, only a few generalities can be made:
1/ No or very little viscosity index improver was used in the oils as this causes intake system deposits.
2/ As more wear occurs at a lower temperature regime than with gasoline, more and different anti-wear additives have been used.
3/ To combat the formation of formic acid, more detergent has been added to the oil. This is indicated by the total base number (TBN), either by ASTM D-664 or D-2896.

4/ An anti-corrosion additive may be included to help alleviate the rusting of engine components.

2.4/ Test Parameters

Phase 3 was intended to complement the work already undertaken in Phases 1 and 2.

Evaluations of the test fleet included the following:
- operation and maintenance during winter conditions;
- engine durability via pre- and post-test engine component measurements, used-oil analysis, and engine cleanliness;
- cold weather driveability and startability; and
- exhaust emissions and fuel consumption to Transport Canada (TC) standards.

2.5/ Test Configuration

The six cars were operated under short-trip (less than 15 km) driving conditions, commonly referred to as "Aunt Minnie" service, under cold engine conditions. The kilometre accumulation was via employee use of the test cars both during and outside working hours.

Components of all six cars were pre-measured:
- cylinder bore diameter, both longitudinal and transverse, at three locations -- top, middle, and bottom of the ring travel region (four sets);
- piston skirt diameter (four);
- ring gap, top and middle rings (four sets);
- ring weight, top and middle rings (four sets);
- rod bearing weights (four sets);
- main bearing weights (five sets);
- ring side clearances, top and middle rings (four sets);
- valve stem diameter, intake and exhaust (four sets);
- valve guide internal diameter, intake and exhaust (four sets);
- valve tip height, intake and exhaust (four sets);
- camshaft lobe heights, intake and exhaust (four sets);
- rocker arm weights (four sets);
- rocker arm pivot weights (four sets);
- valve weights (four sets);
- main bearing journal diameters, horizontal and vertical (five sets);
- connecting rod journal diameters, horizontal and vertical (four sets).

The six cars were rated at the end of the test, by Co-ordinating Research Council (CRC) methods, for the following:

- sludge deposits
  - rocker arm cover
  - front seal housing
  - oil pan
  - valve deck area
  - block underside
- varnish deposits
  - piston skirts
  - rocker arm cover
  - cylinder wall (below ring travel)
  - oil pan
- stuck components
  - rings, lash adjusters
- clogging
  - oil rings, oil screens
- valve deposits

Used-oil analysis was also used to monitor engine durability. The cars had their oil sampled and tested after nominally 1000, 1500, 2000, 2500, 3000, 3500, and 4000 km of operation on the test oil. After a nominal 4000 km accumulation, the engines were torn down, measured, and rated. In Phase 2 of this program, a similar lubricant evaluation was undertaken. However, only 3000 km were accumulated. This increase in distance accumulation was intended to increase the severity of the test.

3/ RESULTS AND DISCUSSION

3.1/ Over-the-Road Fuel Consumption

The fuel consumption results have been grouped by fuel blend. The fuel blend, as previously described, changed over the test period each time the 4546 L (1000 imp. gal) storage tank was refilled.

Table 5 shows the fuel consumption results for the six individual cars. Some effect of the variation in fuel properties, as given in Table 2, would be expected.

The fuel consumption during January and February 1985 was approximately 25% higher than that during June and July 1985. This compares to a value in the 30% range from Phase 2 [2]. The lower value may be due to

- different ambient conditions,
- the probability that the trip length during this phase was longer than that of Phase 2, and
- recalibration of the cars, improving cold weather operation.

The energy content of the three blends in Tables 2 and 5, namely, numbers 9, 10, and 11, was 18.5, 18.4, and 18.3 MJ/L, respectively. The average over-the-road energy consumption would then be 398 MJ/100 km, 333 MJ/100 km, and 311 MJ/100 km, respectively. Transport Canada tests of a gasoline Ford Escort, at a nominal 25°C, gave an urban rating of 9.4 L/100 km, which equates to 303 MJ/100 km [8]. The use of the urban rating is more appropriate because of the short-trip driving regime. This value compares quite well with the average energy consumption of 311 MJ/100 km for blend 11 during June and July 1985.

The Phase 2 results for June and July 1984, with the four Aunt Minnie cars, gave an average fuel consumption of 18.5 L/100 km, which equates to an energy consumption level of 324 MJ/100 km [2]. Comparing the Phase 2, Phase 3, and the Transport Canada (TC) urban rating shows the energy consumption of these three groups to be quite similar during summer.

3.2/ Operational Problems

Table 6 lists the major operational problems reported by the drivers. The driver comments during this phase were not as numerous or detailed as those in Phase 2. This area of the research program is hard to control; it appears that the employees who drove the cars were not as interested in the program as during Phase 2, last winter.

Table 5/ Over-the-Road Fuel Consumption

Blend No.	Time Period	Units	336	337	338	339	340	341	Average
9	Jan. 10/85 to Feb. 20/85	L/100 km	19.11	21.37	21.80	23.78			21.52
		MPIG	14.78	13.22	12.96	11.88			13.13
		L	224	222	199	181			
		km	1172	1039	913	761			
10	Feb. 21/85 to May 15/85	L/100 km	17.15	17.39	19.40	16.25	18.40	20.06	18.11
		MPIG	16.47	16.24	14.56	17.38	15.35	14.08	15.60
		L	183	176	354	256	129	67	
		km	1067	1012	1825	1575	701	334	
11	May 16/85 to July 26/85	L/100 km	17.12	16.94	17.41	15.76	16.42	18.44	17.02
		MPIG	16.50	16.68	16.23	17.92	17.20	15.32	16.60
		L	206	186	43	113	155	340	
		km	1203	1098	247	717	944	1844	

NB: The kilometre accumulation on blends 8 and 12 was insufficient to give meaningful fuel consumption data.

Miles per imperial gallon (MPIG) = 282.48/(L/100 km)
Miles per US gallon (MPUSG) = 235.22/(L/100 km)

Table 6/ Operational Problems

Car No.	336	337	338	339	340	341
COMMENTS						
- Hard to Start	x	x	x	x	x	x
- Stalling During Vehicle Warm-up	x	x	x	x	x	x
- Rough During Vehicle Warm-up (includes - poor idle quality - hesitation)	x	x	x	x	x	x
- Stumble at Shift Changes	x	x	x	x	x	x
- Block Heat Use Reported	x			xx	NA	NA
- No Start Reported	x	x	xx	x	NA	NA
Time to Start/Ambient Temp., s/°C After an Overnight Soak (on fuel blend 9 only)	1/0 6/-6 10/-7 15/-8 6/-9 9/-10 12/-10 6/-12 18/-17 NS/-20	3/+2 5/0 2/-2 4/-5 5/-10 15/-10 30/-20	5/-6 6/-6 10/-6 5/-8 10/-9 7/-10 10/-10 10/-12 25/-13 35/-20	4/-4 5/-4 1/-5 2/-5 4/-9 4/-10 5/-10 9/-10 10/-18 NS/-20	NA	NA
Temp. to Start with 30 s of Cranking (see Figure 1), °C	Estimated average, -18.5				NA	NA

The comments on vehicle performance related to hard startability, stalling during warm-up, rough operation during warm-up (including idle quality and hesitations), and shift change stumble.

Only cars 336, 337, 338, and 339 were used at temperatures significantly below 0°C. The other two cars started late and have not been included in the following analysis of cold startability.

Five no-starts were reported for the four cars, a similar number to that found during Phase 2. Block heat was used three times, for the four cars. Table 6 lists the time to start, in seconds, for a given ambient temperature, in °C, obtained with these four cars after overnight soaks. Figure 1 shows the result graphically. These results are for the most volatile fuel blend, number 9, only.

As seen in Figure 1, an average starting temperature of -18.5°C for 30 s of cranking was found for these four cars. In Phase 2, an average starting temperature of -17.5°C was found with the eight-car fleet. The improvement in cold startability is due to changes in both vehicle calibration and the fuel blend composition.

The fuel used during winter in Phase 2 was basically a 90/10 volume blend of methanol and super non-leaded gasoline spiked with 5 to 6% by mass dimethylether (DME). Fuel blend 9 was a 85/15 volume blend of methanol and super non-leaded gasoline spiked with 6.8% by mass DME. Fuel blend 9 had a dry Reid vapour pressure (RVP) of 122 kPa; in Phase 2 the highest dry RVP reported was 100 kPa. This increase in fuel volatility was partially responsible for the better cold startability during Phase 3.

Vehicle recalibration, undertaken in early January 1985, also affected cold startability and will be discussed later.

In general, the results of this phase indicate better performance than in previous phases, but a similar gasoline-powered vehicle would be expected to have fewer operational problems.

3.3/ Maintenance Problems

The only non-scheduled maintenance in the cars, which could be related to the fuel used, was the recalibration work undertaken in early January 1985. No other maintenance problems were encountered.

However, in Phase 2 the cars in normal use encountered fuel-related problems (i.e., preignition and exhaust gas recirculation deposit problems) not related to initial vehicle tuning or fuel dispensing system problems.

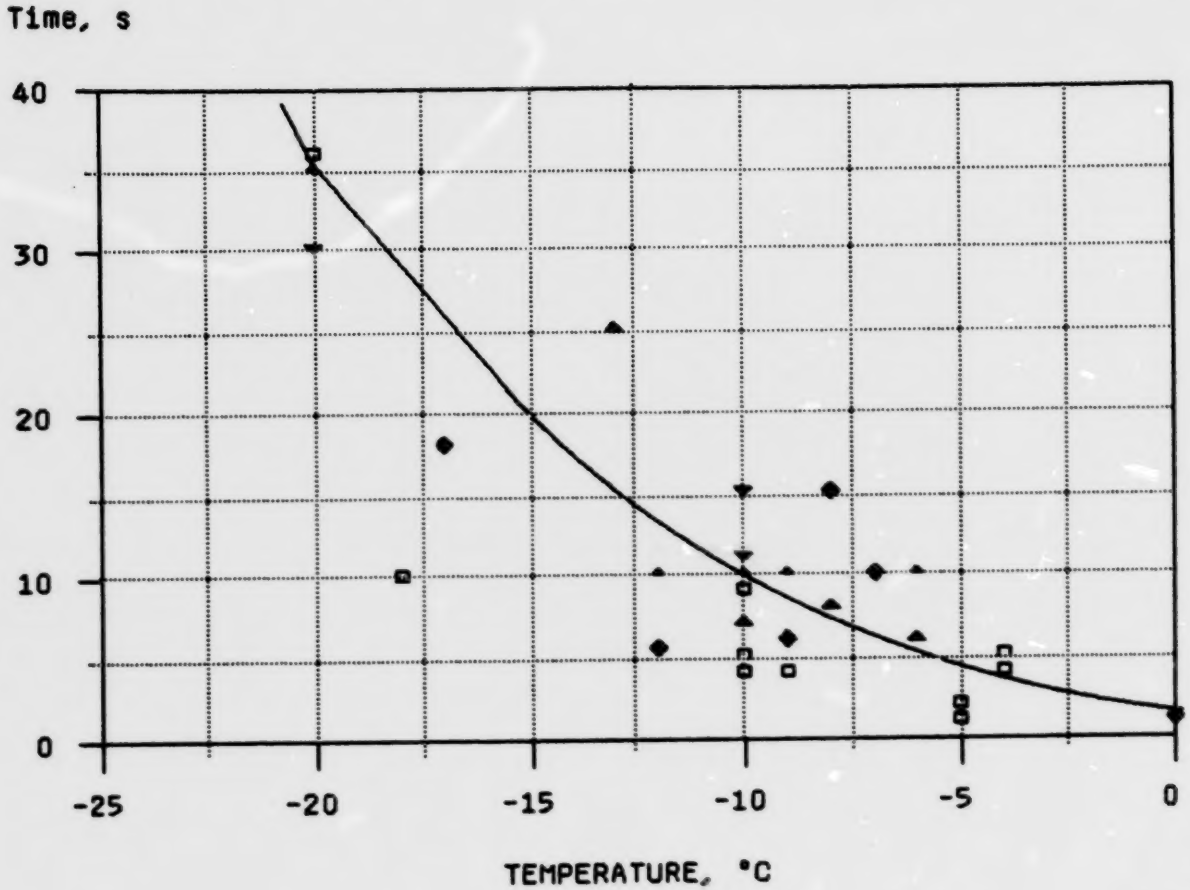


Figure 1/ Temperature vs. Time to Start for Cars 336 to 339

As the cars in this phase were in short-trip service, these problems would not be expected to occur.

3.4/ Oil Consumption

Table 7 lists the oil test matrix. Cars 336 and 337, on oil A, consumed an average of 2.5 L of oil; cars 338 and 339 consumed an average of 1.25 L of oil B; and cars 340 and 341 consumed no oil C.

Normally, in short-trip driving, no oil consumption would be expected. In severe short-trip service, the oil level will generally increase because of fuel dilution. This increase occurred with these cars, but these cars could lose oil if the sump temperature exceeded 64°C, the boiling point of methanol.

When the sump temperature exceeds 64°C with some (i.e., greater than 5 to 10% by volume) fuel-methanol emulsified in the engine oil, the fuel will start to boil. This increases the crankcase pressure, which is then relieved by venting some of the foamy oil-fuel mixture through the positive crankcase ventilation (PCV) system or past any seals or, possibly, the piston rings. Some of the oil is then lost, and usually large clouds of blue-grey smoke occur.

Some method of controlling this sudden boiling and expulsion of both fuel and oil from the sump must be devised or possible engine damage due to loss of oil, environmental concern over the cloud of acrid blue-grey smoke, or an ensuing sump explosion could possibly occur.

3.5/ Used-Oil Analysis

Tables 8, 9, and 10 show the average used engine oil test results for oils A, B, and C, respectively. Table 4 lists the three test oil inspection properties. Appendices B and C show infrared transmission graphs for new and used oils.

All the pentane insolubles results were acceptable (Figure 2). Pentane insolubles include oil insoluble matter caused by contamination and oil or additive package degradation. A high value of pentane insolubles indicates that the oil can no longer hold contaminants in solution. The insolubles level in this phase are less than the short-trip cars in Phase 2 and are comparable to the levels in the normal-service cars in Phase 2. This may be due to the change from the original high-ash oil additive package used in Phase 2.

Table 7/ Oil Test Matrix

Car No.	336	337	338	339	340	341
Oil Type	A	A	B	B	C	C
Oil Grade	10W20	10W20	10W30	10W30	10W20	10W20
AL Number	41036	41036	41059	41059	50223	50223
Initial km Reading	5055	26 222	26 323	26 371	26 248	10 012
Final km Reading	9108	30 514	30 464	30 729	30 268	13 972
km on Oil	4053	4 292	4 141	4 358	4 020	3 960
Oil Consumption, L	2.5	2.5	0.5	2.0	0.0	0.0
Oil Consumption, km/L	1600	1 700	>5 000	2 200	>5 000	>5 000

NB: Oil consumption rates of greater than the drain period of 5000 km are considered equivalent.

Table 8/ Oil A -- Average Used Engine Oil Test Results

Oil A, 10W20, AL 41036, Paramins, Cars 336 and 337

▲ km	0	710[1]	1503	2291	2759	3402	3806	4173
Visc. at 100°C	8.73	FD	FD	7.78	7.81	7.80	7.85	7.94
at 40°C	56.29							49.42
Pentane Insol.	0.00	0.74	0.29	0.38	0.25	0.26	0.43	0.37
Al	0	7.3	10.6	11.8	12.1	11.2	10.7	12.4
Cr	0	2.6	9.0	10.6	8.2	7.1	7.5	7.7
Cu	0	12.8	20.3	30.9	38.1	35.0	7.4	27.5
Fe	0	26.4	40.5	63.8	81.3	66.3	145.5	75.5
Pb	0	29.2	41.0	49.8	60.3	54.2	29.7	30.2
Si	0	23.1	32.1	32.2	31.0	13.4	36.2	25.0
TANe, D-664 mgKOH/g	2.0							2.9
TBNe, D-664 mgKOH/g	14.0							6.3
TBNe, D-2896 mgKOH/g	14.8							12.8
Fuel Dilution, D-322, %Vol.	0.0							0.4

[1] - 336 only FD-Fuel Dilution

Table 9/ Oil B -- Average Used Engine Oil Test Results

Oil B, 10W30, AL 41059, Lubrizol, Cars 338 and 339

Δ km	0	1434	2522	2952	3496	4250
Visc. at 100°C	10.87	FD	FD	FD	8.28	8.41
at 40°C	68.11		81.02			50.49
Pentane Insol.	0.0	0.29	0.25	0.31	0.19	0.34
Al	0	7.8	15.2	21.3	10.7	12.0
Cr	0	5.5	10.0	18.4	7.9	19.3
Cu	0	11.9	21.7	25.8	24.8	30.2
Fe	0	31.7	33.0	58.1	86.1	108.0
Pb	0	15.5	19.3	26.8	26.8	62.6
Si	0	31.2	32.8	40.5	34.6	50.0
TANe, D-664 mgKOH/g	2.7					2.0
TBNe, D-664 mgKOH/g	6.2					4.0
TBNe, D-2896 mgKOH/g	10.3					7.6
Fuel Dilution, D-322, %Vol.	0.0					0.7

Table 10/ Oil C -- Average Used Engine Oil Test Results

Oil C, 10W20, AL 50223, Shell Canada, Cars 340 and 341

Δ km	0	508[1]	1002[1]	1564	2007	2661	3015	3541	3990
Visc. at 100°C	7.79	7.37	FD	FD	7.41	7.57	7.57[2]	7.61[2]	7.62
at 40°C	51.41						49.05[1]		49.54
Pentane Insol.	0.0	0.05	0.07	0.17	0.16	0.36	0.44	0.37	0.27[2]
Al	0	7.2	9.1	11.1	8.8	13.3	14.5	14.6	15.6
Cr	0	5.1	13.0	18.1	11.4	17.5	24.0	27.4	24.3
Cu	0	6.7	12.0	12.6	17.1	24.0	26.4	26.1	33.7
Fe	0	25.1	33.2	46.9	45.4	67.0	78.5	87.7	92.0
Pb	0	14.5	22.6	26.0	27.6	36.3	49.9	41.6	46.5
Si	0	38.2	12.4	60.8	63.2	50.5	59.6	72.2	93.1
TANe, D-664 mgKOH/g	2.5								3.2
TBNe, D-664 mgKOH/g	12.9								11.6
TBNe, D-2896 mgKOH/g	14.2								13.0
Fuel Dilution, D-322, %Vol.	0.0								0.5

[1] - 341 only
[2] - 340 only

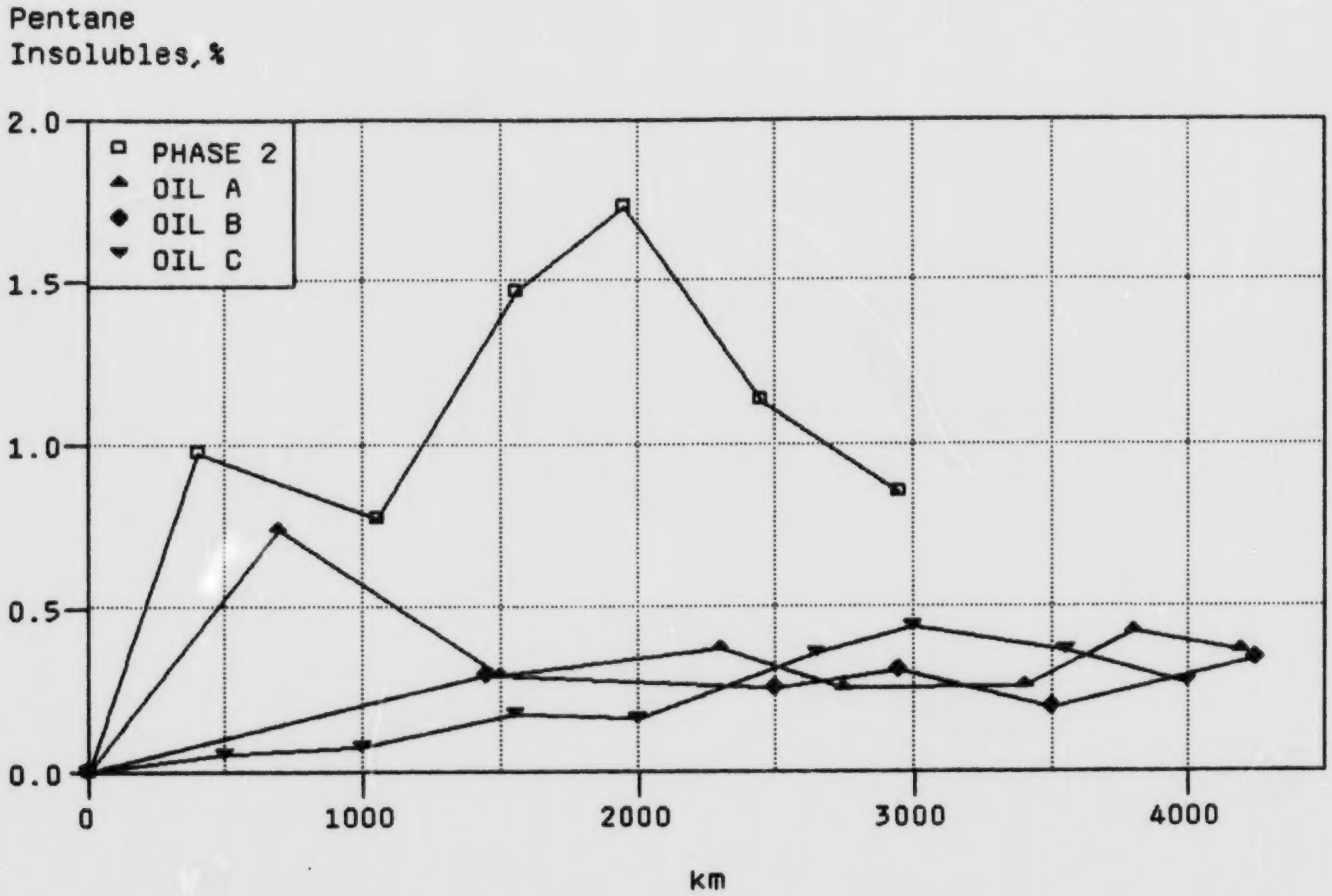


Figure 2/ Used-Oil Analysis -- Average Pentane Insolubles vs. Distance Accumulation

Oils A and C used no viscosity index improver (VII), being rather narrow multi-grade oils. A VII was not used because of the problems of intake system deposits encountered in the German BMFT trial [7,9] with oils containing said components. The viscosity measurements showed that oils A and, especially, C showed little reduction in viscosity over the test.

Oil B showed a larger reduction in viscosity over the test period; this is expected because of the use of a VII. Oil B was also the only oil tested for viscosity at 40°C when the results at 100°C were invalid due to excessive fuel dilution (as any fuel dilution boils out of the oil suddenly at about 64°C). The tests showed that the 40°C viscosity was significantly higher, namely, 81 centistokes (cSt), when there was an emulsion of fuel and oil, versus 68 cSt for the new oil.

This increase in oil viscosity when there is excessive fuel dilution would cause poorer startability as the cranking speed of the engine would be reduced.

Fuel dilution levels, as indicated by the ASTM D-322 test, which will not detect water soluble fuels such as methanol, were low. The fuel dilution level as reported should give an indication of the amount of hydrocarbon fuel dilution, which constituted 15% by volume of the fuel blend.

The D-664 total acid number (TAN) indicates the relative amount of acidic constituents in the oil. The increase in TAN should give an indication of lubricant degradation in service. The results with the three oils over the approximate accumulation of 4000 km of short-trip driving show an increase on the order of one number or less.

The D-664 total base number (TBN) indicates the relative amount of basic constituents in the oil. As the lubricant degrades, the TBN should decrease. The TBN of all three oils dropped. Oil A dropped the most; oil C, the least.

The D-2896 TBN also indicates the relative amount of basic constituents in the oil. All three oils dropped in the value of this TBN as well. The drop in TBN was not very consistent either between the two tests or between cars on the same oil.

Wear metals, in parts per million (ppm) can be used to infer the condition of the engine. Appendix D shows some data which give basic warning levels for used-oil analysis.

The aluminum levels were roughly equivalent for the three candidate oils and generally acceptable being between 10 and 20 ppm (Figure 3).

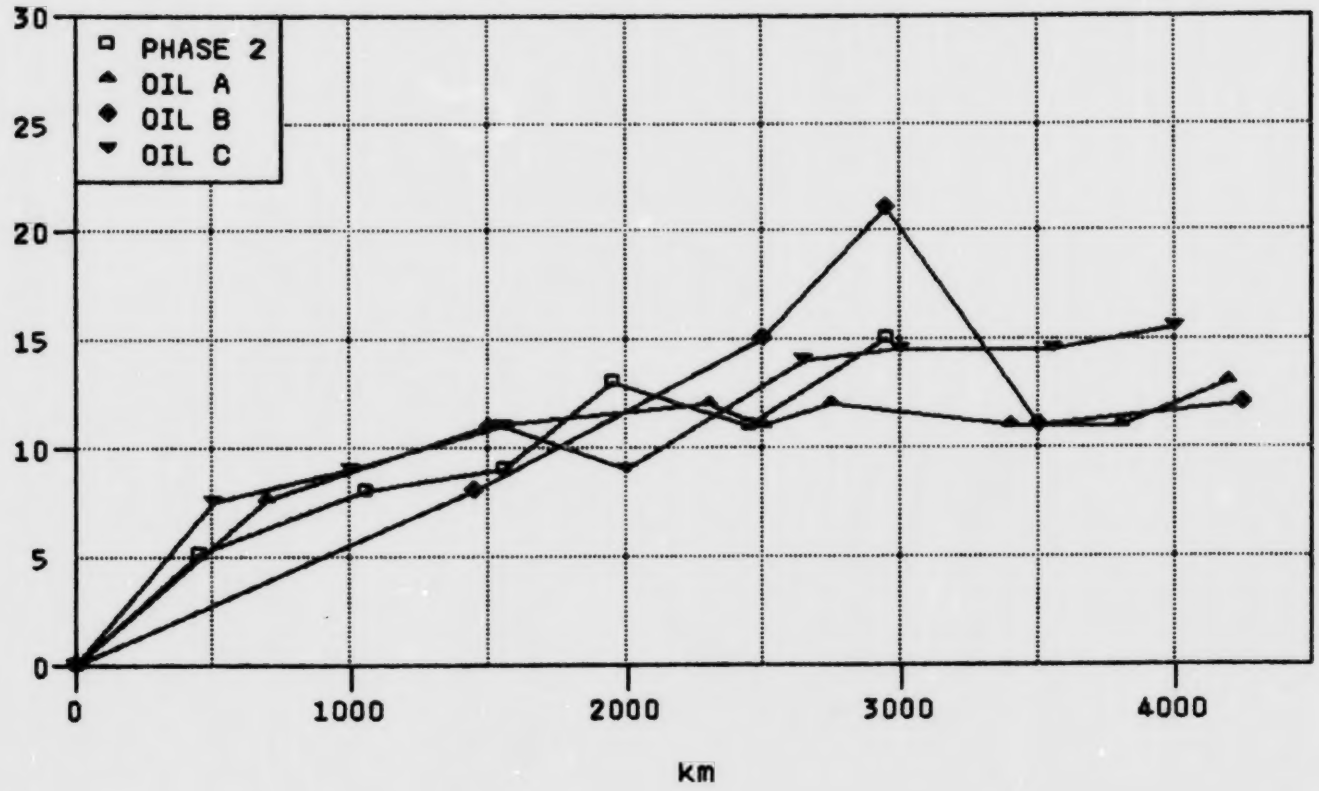


Figure 3/ Used-Oil Analysis -- Average Aluminum vs. Distance Accumulation

However, they are higher than the Phase 2 results.

The chromium levels would indicate ring wear, and the results, in increasing order, were oil A, B, then C, which reflects the ring gap growth (to be discussed later). The levels ranged from less than 10 up to 27 ppm (Figure 4). This is much higher than in Phase 2.

The copper levels were roughly equal for the three oils, at between 20 and 30 ppm for most of the test (Figure 5). The copper would be expected to come from the thrust bearing on the top half of the number three main bearing, which consistently gave the highest weight loss of the five main bearings. There is no overlay on the thrust portion of this bearing, so any wear would be expected to increase copper levels in the oil. The copper levels in Phase 2 were generally much higher.

The iron levels were lowest for oil A, then C, then B (Figure 6). This concurs with the amount of camshaft wear (as discussed later) with the three oils. The iron levels for all three oils were generally less then Phase 2 results.

The lead levels, which would come from the terneplate filler neck in the fuel tank and the bearings, ranged up to 63 ppm (Figure 7). In Phase 2, the lead levels were generally between 100 and 200 ppm, with the average final reading over 600 ppm.

The silicon level is generally taken to indicate dirt ingestion and should be in the 10 to 20 ppm range (Figure 8). In Phase 2, the long-distance cars did attain this figure but were initially higher, indicating, possibly, corrosion of some metallic component containing silicon (i.e., the cast-iron block, the aluminum alloy intake manifold, and head). In this phase, the three different oils give different results: namely, oil A was in the 20 to 30 ppm range, B was in the 30 to 50 ppm range, and C was in the 50 to 90 ppm range over the test period.

3.6/ Engine Ratings

All six cars were dismantled at the end of the test and rated for sludge and varnish deposits, clogging, stuck components, intake valve deposits, and valve deposit weights. The procedures followed accepted industry standards for the field evaluation of lubricants. A number of references are summarized in Appendix E.

Table 11 shows the engine ratings; Table 12 shows the valve deposit ratings and weights. The results from Phase 2, with the four Aunt Minnie cars, are also presented for comparison purposes. The Aunt Minnie cars

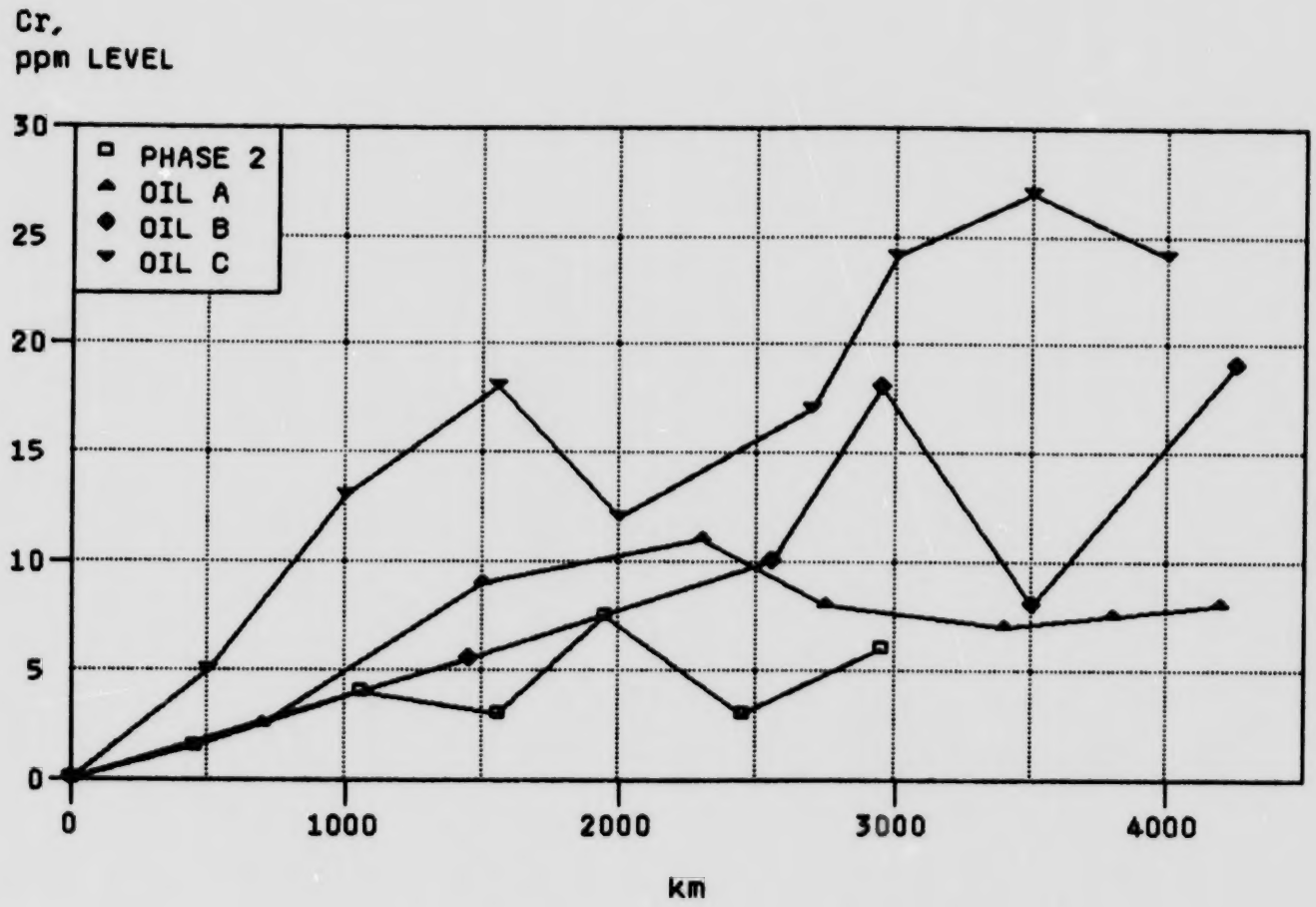


Figure 4/ Used-Oil Analysis -- Average Chromium vs. Distance Accumulation

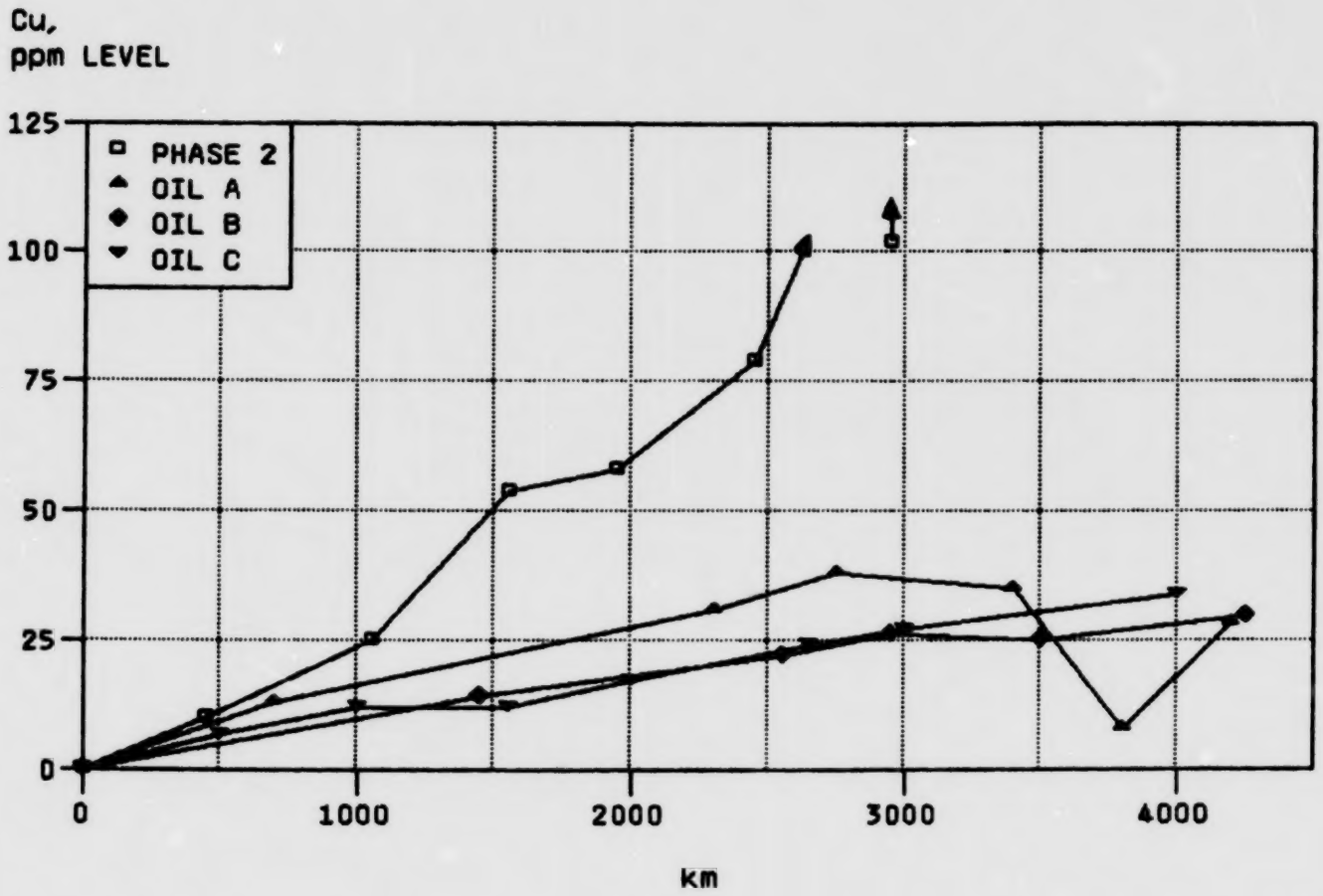


Figure 5/ Used-Oil Analysis -- Average Copper vs. Distance Accumulation

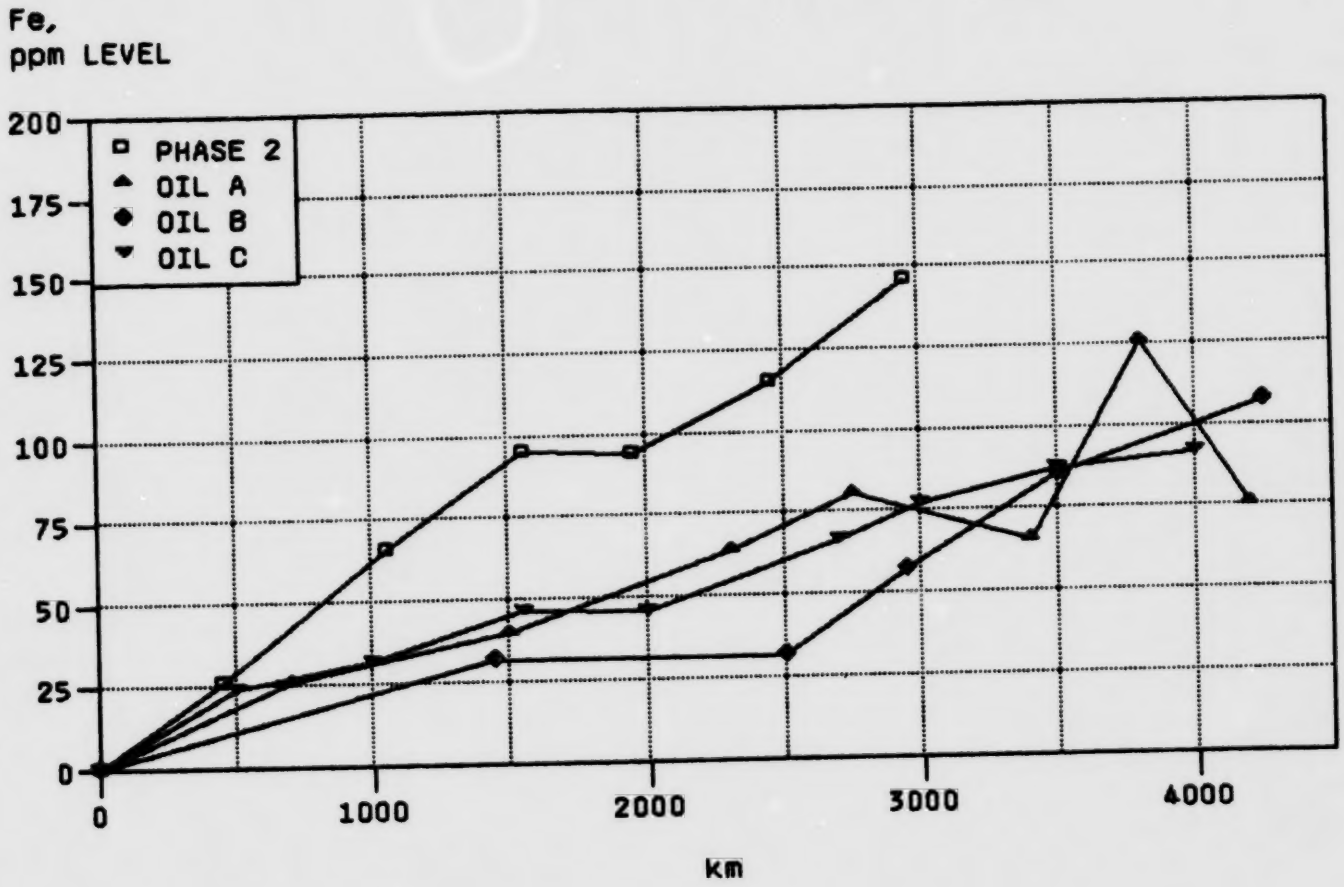


Figure 6/ Used-Oil Analysis -- Average Iron vs. Distance Accumulation

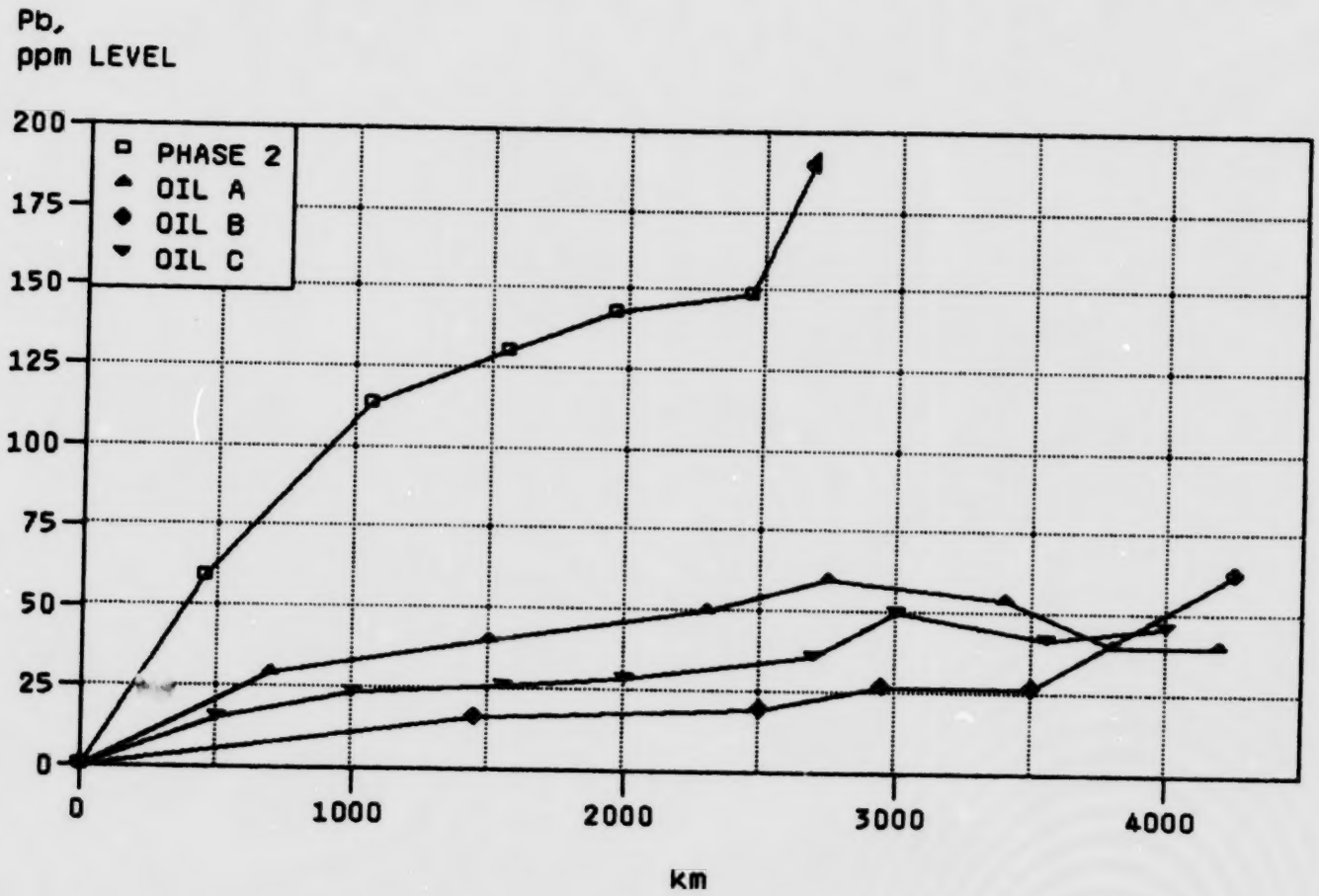


Figure 7/ Used-Oil Analysis -- Average Lead vs. Distance Accumulation

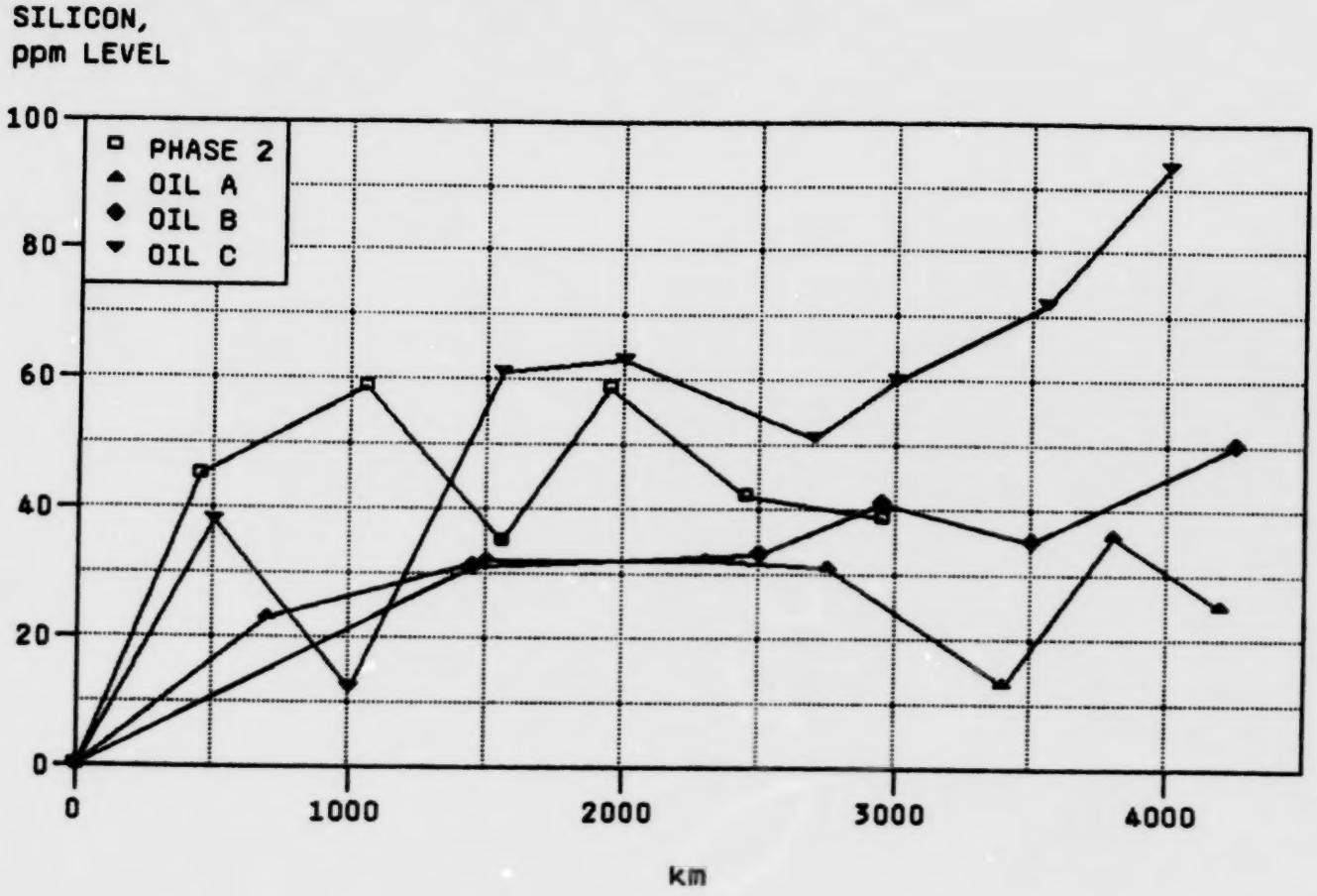


Figure 8/ Used-Oil Analysis -- Average Silicon vs. Distance Accumulation

Table 11/ Engine Ratings

Car No.	Oil A, 10W20 336	337	Avg.	Oil B, 10W30 338	339	Avg.	Oil C, 10W20 340	341	Avg.	Original Oil Phase 2 Avg.(4 Cars)
Sludge Deposits*										
Rocker Arm Cover	9.84	9.90	9.87	9.76	9.76	9.76	9.75	9.75	9.75	9.81
Front Seal Housing	9.88	9.82	9.85	9.75	9.75	9.75	9.82	9.75	9.79	9.85
Oil Pan	9.70	9.80	9.75	9.64	9.71	9.68	9.66	9.69	9.68	9.57
Valve Deck	9.73	9.67	9.70	9.70	9.75	9.73	9.73	9.69	9.71	9.84
Block Underside	9.82	9.67	9.75	9.70	9.75	9.73	9.67	9.67	9.67	9.86
Average Sludge	9.79	9.77	9.78	9.71	9.74	9.73	9.73	9.71	9.72	9.79
Varnish Deposits*										
Piston Skirts	9.15	9.23	9.19	9.18	9.10	9.14	9.24	9.14	9.19	9.35
Rocker Arm Cover	9.02	8.31	8.67	8.90	9.12	9.01	8.76	8.55	8.66	9.15
Cylinder Wall	9.37	9.51	9.44	8.96	8.93	8.95	9.26	9.23	9.25	9.39
Oil Pan	8.51	8.24	8.38	8.73	8.47	8.60	8.77	8.24	8.51	9.18
Average Varnish	9.01	8.82	8.92	8.94	8.90	8.92	9.01	8.79	8.90	9.27
Clogging										
Oil Ring, %	0	0	0	0	0	0	0	0	0	0
Oil Screen, %	0	0	0	0	0	0	0	0	0	0
Stuck Comp. Rings, No.	0	0	0	0	0	0	0	0	0	0
Stuck Oil Rings, No.	0	0	0	0	0	0	0	0	0	0
Stuck Lash Adj. Bodies, No.	0	0	0	0	0	0	0	0	0	0
Stuck Lash Adj. Plungers, No.	0	0	0	0	0	0	0	0	0	0

*10 = clean

Table 12/ Engine Valve Ratings

Car No.	336	337	Avg.	338	339	Avg.	340	341	Avg.	Phase 2 Avg.(4 Cars)
Intake Valve Deposits, Rating										
1	8.5	9.0	8.8	9.0	9.0	9.0	9.5	9.5	9.5	9.0
2	8.0	8.5	8.3	9.0	8.3	8.7	9.5	9.5	9.5	8.7
3	8.3	8.8	8.6	8.5	8.3	8.4	9.5	9.5	9.5	8.8
4	8.5	9.0	8.8	8.5	8.8	8.7	9.5	9.5	9.5	8.9
Average	8.3	8.8	8.6	8.8	8.6	8.7	9.5	9.5	9.5	8.8
Intake Valve Deposit Wt.,g										
1	0.313	0.138	0.226	0.432	0.125	0.279	0.093	0.091	0.092	0.286
2	0.482	0.166	0.324	0.169	0.284	0.227	0.088	0.106	0.097	0.289
3	0.322	0.282	0.302	0.372	0.242	0.307	0.079	0.095	0.087	0.240
4	0.347	0.260	0.304	0.413	0.322	0.368	0.108	0.184	0.146	0.246
Average	0.366	0.212	0.289	0.347	0.243	0.295	0.092	0.119	0.106	0.265
Exhaust Valve Deposit Wt.,g										
1	0.195	0.321	0.258	0.126	0.197	0.162	0.088	0.077	0.083	0.200
2	0.130	0.115	0.123	0.074	0.095	0.085	0.069	0.072	0.071	0.167
3	0.140	0.099	0.121	0.138	0.106	0.122	0.067	0.065	0.066	0.174
4	0.280	0.194	0.240	0.130	0.147	0.139	0.067	0.143	0.105	0.179
Average	0.186	0.182	0.184	0.117	0.136	0.127	0.073	0.089	0.081	0.180

in Phase 2 only accumulated 3000 km before inspection. The Phase 3 cars accumulated 4000 km.

The sludge ratings were all very good, in the 9.7 to 9.8 range (where 10 = clean), with no real difference between the three candidate oils. The Phase 2 result for sludge was 9.8. In general, it appears that cars operated on M90 or M85 fuel have very low sludging tendencies.

The engine varnish level was almost identical for the three oils, namely, 8.9. The Phase 2 level for Aunt Minnie service was 9.3. The higher varnish level indicates that the general engine temperatures were higher in this Phase 3 test than during the Phase 2 test.

No clogged or stuck components were found in the six test cars, which is identical to the Phase 2 results.

The intake valve deposit ratings, as given in Table 12, were good. Oils A and B were similar to the Phase 2 results (8.6, 8.7, and 8.8, respectively). Oil C was 9.5, which is a very good result. The valve deposits rated are only those on the stem and the back of the valve, not the valve face.

The intake valve deposit weights were similar to Phase 2 for oils A and B, and much less for oil C. In Phase 2, the majority of the deposits were on the valve face, whereas, in this phase, very few deposits were found there. This is probably related to the much lower sulphated ash level in oils A, B, and C compared to the Phase 2 oil (about 1.5% by mass versus 2.9% by mass).

The exhaust deposit weights were also obtained. The order of the amount of deposit was similar to that of the intake valves, specifically oil C was the best, then oil B, with Phase 2 and oil A having the most deposits. Again, in Phase 2, there were very hard deposits on the valve faces, which were not present with any of the oils in this phase.

3.7/ Engine Wear Results

Table 13 details the dimensional changes in the six cars over the test. All three candidate oils showed low and generally equivalent wear in cylinder bore diameter, piston skirt diameter, ring side clearances, valve stem diameter, valve guide internal diameter, valve tip height, and both connecting rod and main bearing journals.

Camshaft lobe height change was lowest with oil A and highest with oil B. Oil C and the Phase 2 results were in between. Ring gap growth was

Table 13/ Engine Wear Results -- Dimensional

	336	337	Avg.	338	339	Avg.	340	341	Avg.	Phase 2 Avg.(2 Cars)
Cyl. Dia. Long., in.	0.0001	0.0004	0.0003	0.0000	0.0004	0.0002	0.0002	0.0002	0.0002	0.0001
Trans., in.	0.0003	0.0003	0.0003	0.0001	0.0004	0.0003	0.0002	0.0003	0.0003	0.0002
Piston Skirt Dia., in.	0.0002	0.0002	0.0002	0.0004	0.0001	0.0003	0.0001	0.0001	0.0001	0.0003
Ring Gap Growth(Top), in.	0.0010	0.0010	0.0010	0.0035	0.0020	0.0028	0.0035	0.0040	0.0038	0.0005
(Middle), in.	0.0015	0.0040	0.0028	0.0040	0.0045	0.0043	0.0035	0.0005	0.0020	0.0015
Ring Side Clearance(Top), in.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0006	0.0000	0.0003	0.0010
(Middle), in.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003	0.0000	0.0002	0.0001
Valve Stem Dia.(I), in.	0.0000	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001
(E), in.	0.0001	0.0005	0.0003	0.0004	0.0001	0.0003	0.0001	0.0003	0.0002	0.0001
Valve Guide Dia.(I), in.	0.0000	0.0000	0.0000	0.0001	0.0002	0.0002	0.0003	0.0002	0.0003	0.0003
(E), in.	0.0001	0.0001	0.0001	0.0001	0.0005	0.0003	0.0002	0.0006	0.0008	0.0003
Camshaft Lobe (I), in.	0.0002	0.0004	0.0003	0.0012	0.0019	0.0016	0.0007	0.0005	0.0006	0.0011
(E), in.	0.0001	0.0002	0.0002	0.0011	0.0018	0.0015	0.0009	0.0011	0.0010	0.0009
Valve Tip Ht.(I), in.	0.0011	0.0007	0.0009	0.0003	0.0008	0.0006	0.0003	0.0007	0.0005	0.0013
(E), in.	0.0004	0.0000	0.0002	-0.0012	0.0004	-0.0004	0.0002	0.0004	0.0003	0.0007
Journals - Con Rod, in.	0.0000	0.0002	0.0001	0.0001	0.0000	0.0001	0.0008	0.0002	0.0001	0.0002
Main, in.	0.0000	0.0001	0.0001	0.0002	0.0001	0.0002	0.0008	0.0001	0.0001	0.0002
Other Remarks	Crankshaft journals stained. Camshaft lobes rusted. Cyl. bore rust (slight).	Crankshaft journals stained. Cyl. bore rust.		Crankshaft journals stained. Cyl. bore rust (slight).	Crankshaft journals stained. Cyl. bore rust (slight).		Cyl. bore scores (slight).	Rust on valve stems. Cyl. bore rust (slight).		Crankshaft journals stained. Camshaft lobes rusted. Lifters stained. Cyl. bore rust (slight).

NB: In phase 2, only 3000 km were accumulated vs 4000 km in this phase.

higher in this phase than in Phase 2. Oil A gave the minimum amount of increase, oil C next, then oil B. The larger values of gap growth may be due to the use of the same rings as in Phase 2. Possibly, with brand new rings, the wear would have been lower.

All three oils showed some evidence of stained crankshaft journals, rusted camshaft lobes, and cylinder rusting. Car 340 showed some scoring of the cylinder bore; this is a carry-over from Phase 2. Car 341 had rust deposits on the exhaust valve stems.

Table 14 gives the weight losses over the test. The change in ring weight, after cleaning, reflects the increase in ring gap growth, previously mentioned. Oil A gave the least decrease in weight, then B, then C. The Phase 2 oil result was better than any of the Phase 3 oils.

The rod and main bearing weight losses were all less than Phase 2. Oil B gave the best results, then C, then A. Oil B gave the highest amount of wear on both the rocker arm and its pivot. Oils A, C, and the Phase 2 results were all much lower.

3.8/ Engine Durability

In general, all the three oils gave equivalent performance. Some rusting of various components was evident. Some camshaft wear also occurred. The only area of major wear was in ring gap growth or ring weight loss. As previously mentioned, the same rings were used as in Phase 2. These top rings are chrome plated, so it is possible that with brand new rings the wear would have been reduced.

The used-oil analysis results generally reflect the engine measurements: namely, chromium levels were lowest with oil A, which also had the lowest ring gap growth, and highest with oil C, which had the highest ring gap growth. The iron levels paralleled the camshaft wear figures.

Further differentiation between the three candidate oils requires a longer term test, similar to that now being undertaken in Phase 4. This short-trip driving test was not sufficiently severe to allow good differentiation between the three oils.

3.9/ Cold Weather Operation -- January Program

A total of 12 nominally identical Ford Escorts were tested for both cold startability and cold driveability in association with personnel from Ford's Scientific Research Laboratory in Dearborn, Michigan during January 1985.

Table 14/ Engine Wear Results -- Weight

	336	337	Avg.	338	339	Avg.	340	341	Avg.	Phase 2 Avg.(2 Cars)
Ring Wt. (Top), g	0.0275	0.0344	0.0310	0.1015	0.0472	0.0744	0.0678	0.1625	0.1152	0.0114
Cleaned Loss (Middle), g	0.0100	0.0133	0.0117	0.0204	0.0132	0.0168	0.0232	0.0477	0.0355	0.0126
Rod Brng Wt. Loss (Top), g	0.0125	0.0120	0.0123	0.0051	0.0055	0.0052	0.0085	0.0096	0.0090	0.0140
(Btm.), g	0.0057	0.0001	0.0029	0.0023	0.0009	0.0016	0.0013	0.0040	0.0026	0.0050
(Both), g	0.0182	0.0121	0.0152	0.0074	0.0064	0.0069	0.0098	0.0136	0.0115	0.0190
Main Brng Wt. Loss (Top), g	0.0499	0.0366	0.0433	0.0181	0.0225	0.0203	0.0239	0.0303	0.0271	0.0718
(Btm.), g	0.0076	0.0005	0.0041	0.0050	0.0049	0.0050	0.0037	0.0103	0.0070	0.0126
(Both), g	0.0576	0.0371	0.0473	0.0231	0.0274	0.0252	0.0276	0.0406	0.0341	0.0844
Rocker Arm Wt. Loss (I), g	-0.0030	0.0041	0.0006	0.0239	0.0234	0.0237	0.0042	-0.0021	0.0011	0.0071
(E), g	-0.0030	0.0019	-0.0006	0.0272	0.0225	0.0249	0.0044	-0.0014	0.0015	0.0095
Rocker Arm Pivot Wt. Loss (I), g	0.0189	0.0031	0.0110	0.0306	0.0643	0.0475	0.0162	-0.0327	-0.0083	-0.0025
(E), g	0.0003	0.0011	0.0007	0.0421	0.0514	0.0468	0.0220	-0.0298	-0.0039	0.0080

NB; In phase 2, only 3000 km were accumulated vs 4000 km in this phase.

The testing variables included both hardware changes and fuel blend modifications. The test procedure used was that developed by the Ford Motor Company for cold-start and choke evaluation.

The procedure is similar to that normally used at the Oakville Research Centre (ORC) and previously used in this program. Specifically, the car is started, followed by a 10 s idle on high cam in park, 10 s at curb idle in park, then 10 s in drive. This is followed by a series of 0 to 32.2 km/h (20 mph) accelerations at a part throttle vacuum between 17 kPa (5 in. Hg) and 34 kPa (10 in. Hg), 0.3 km (0.2 mi) apart. The driveability is rated at engine idle (satisfactory, loading, rough, and/or stall); under drive acceleration (satisfactory, lean, loading, stumble, backfire, and/or hesitation); and for operation at road load (32.2 km/h [20 mph]) (satisfactory, lean, chuckles, and/or backfires). "Chuckles" is the term used by Ford for surge. No rating scale is normally used. Table 15 lists the ORC cold driveability test procedure.

For the purposes of this program, a rating scale of 18 demerits per stall, eight demerits per other malfunction, and one demerit per second of cranking to start was used. This allows the various different fuels and hardware changes to be compared quantitatively.

Tests were performed on the cars at -5 and -15°C. Initially, three test fuels were used (Table 16).

The three test fuels were a 90% methanol (MeOH)/10% super non-leaded winter-grade (SNL-W) by volume blend, a 85% MeOH/15% SNL-W by volume blend, and the latter blend spiked with 6.8% by mass DME. The 90/10 blend was dropped almost immediately due to its poor performance.

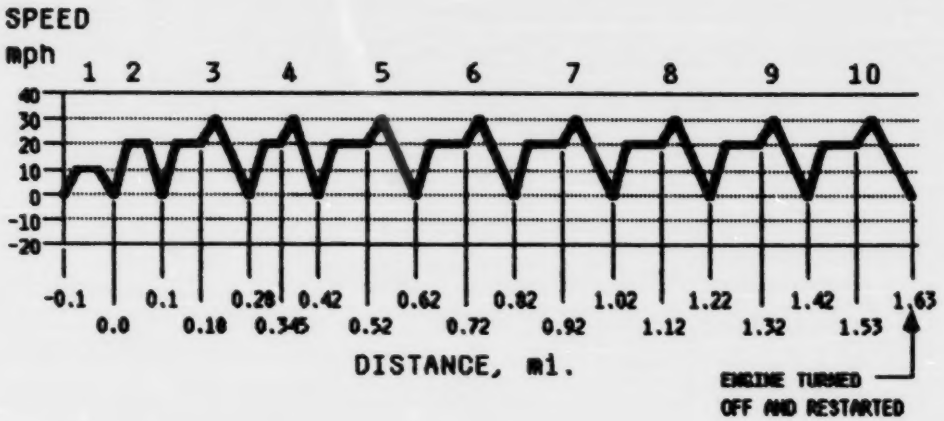
The hardware changes, developed by Ford in Dearborn, based on the startability at -17°C (0°F) included the following:

- Choke Setting Changes
  - a tighter pull-down to 2.5 mm.
  - a richer choke setting (by 2°), which causes the choke to stay on for a longer time period.

- Vacuum Advance Routing Changes
  - allowing manifold vacuum to the distributor at engine coolant temperatures below 53°C (128°F).

- Various Recall Changes on the Gasoline Version
  - new vented distributor cap, due to corrosion problems.
  - new rotor.

Table 15/ Cold Driveability Test Procedure



Steps 6 to 10 are repeated two more times.

1. The engine is started according to the manufacturer's recommended starting procedure. It is allowed to idle for 10 s in neutral at fast idle, for 10 s in neutral at reduced rpm, and for 10 s in a gear.

2. The initial drive-away (step 1) consists of a part-throttle acceleration to 10 mph (16.1 km/h), a short cruise at that speed, deceleration to a full stop, and a 5 s idle period.

3. The second drive-away mode (step 2) consists of a full-throttle acceleration to 20 mph (32.2 km/h), a short cruise at that speed, deceleration to a full stop, and a 5 s idle period.

4. Steps 3-20 are practically identical. They consist of a part-throttle acceleration to 20 mph (32.2 km/h), a short cruise at that speed, a full-throttle acceleration to 30 mph (48.3 km/h), a short cruise at that speed, deceleration to a full stop, and a 5 s idle period.

5. After the 10th and the 15th step, the engine is turned off for 10 s and restarted.

Table 16/ Test Fuel Properties

FUEL NAME	90/10		85/15		85/15/DME	
COMPONENTS	% Vol.	% Mass	% Vol.	% Mass	% Vol.	% Mass
Methanol (MeOH)	90.0	90.6	84.0	84.8	77.7	79.4
Super Non-Leaded Gasoline -- Winter Grade (SNL-W)	10.0	9.4	16.0	15.2	14.7	14.2
Dimethylether (DME)	0.0	0.0	0.0	0.0	7.6	6.4
PROPERTIES						
RVP (Dry), kPa	49.6		56		122	
RVP (Dry), (psi)	(7.2)		(8.1)		(17.7)	
ASTM D-86 Distillation:						
IBP, °C	50		49		31	
10%, Evap., °C	63		62		45	
50%, Evap., °C	64		64		64	
90%, Evap., °C	64		65		65	
EP, °C	66		65		169	
% Recovery	98.9		98.8		94.1	
Density, kg/L	0.791		0.789		0.780	

  - new coil wire, due to corrosion problems.
  - new thermostat 88.8°C (192°F) due to initial batches of thermostats not closing fully, thereby increasing warm-up time substantially.

- Spark plug gap change an increase to a 0.112 cm (0.044 in) gap from the initial 0.086 cm (0.034 in) recommendation with the AGSF12C plugs.

These changes cause a richer mixture for initial starts, so a new starting procedure with fewer pump shots was also developed (Table 17).

The changes to the distributor vacuum arrangement should reduce hesitation on shift change. The thermostat change should decrease the total warm-up time. The distributor and spark plug changes should allow a better spark, improving cold weather driveability.

Tests were performed over a one-week period (Tables 18 and 19): two days at about -15°C and two days at about -6°C. Initially, all three fuels (Table 15) were tested at -14°C. Only one car was operated on the 90/10 blend, and it failed to start. A comparison between the 85/15 and 85/15/DME fuels showed that the 85/15/DME fuel had approximately 40% of the demerits of the 85/15 fuel, at -15°C. Further testing at -16°C showed that five out of six cars failed to start on the 85/15 blend, whereas only one out of six cars failed to start on the 85/15/DME blend. In general, the dry RVP of the two fuels indicated their relative performance.

Based on these cold startability tests and previous work, the 85/15 blend would be expected to allow starting, with 30 s of cranking, down to -15°C. The 85/15/DME blend should allow 30 s starts to about -20°C. The 90/10 blend would be in the -10°C range with 30 s of cranking.

The RVP (dry) of the 85/15/DME blend was 122 kPa (17.7 psi); this is over the present limit for gasoline in Canada (103 kPa [15.0 psi]). It would be unreasonable to assume that near-neat methanol fuels would be allowed a higher RVP level than gasoline. The results indicate that an 85/15/DME type blend of 103 kPa (15.0 psi) should allow 30 s starts down to -18°C.

The modifications recommended by Ford Motor Company also gave some benefit. The actual lower startability limit did not seem to drop; however, the time to start at a given temperature was lower. The modifications dropped cold-start times to approximately 70% of their prior level and cold driveability demerits to approximately 60% of their prior level. The effect was reduced with the better performing 85/15/DME fuel, compared to the 85/15 fuel.

Table 17/ Revised Starting Procedure

METHANOL CARS

STARTING PROCEDURE REVISION: FEBRUARY 1985

COLD ENGINE

1. Depress accelerator pedal twice SLOWLY.
2. Turn ignition on.
3. Wait 10 s or until seat belt buzzer goes off.
4. Turn key to start until engine starts, then release key.
5. If engine fails to start in 15 s, wait 5 s and repeat steps 1 through 4.

WARM ENGINE

1. Turn ignition on.
2. Depress accelerator pedal 1/3 to 1/2.
3. Holding accelerator pedal down, turn key to start until engine starts, then release key.

DO NOT PUMP PEDAL

Table 18/ Test Results at Approximately -15°C

	Jan. 15/85 at -14°C							Jan. 16/85 at -16°C				
Time to First Fire, s	10	7	9	2	5	4	9	10	2	4	3	4
Time to Start, s		40	26	11	8	7	26		25		12	13
Idle Quality Demerits	-	48	58	19	20	40	24	-	129	-	28	32
Drive Accel. Demerits	-	84	8	30	12	0	0	-	43	-	20	32
Road Load Demerits	-	0	0	0	0	0	0	-	16	-	4	8
Drivesbility Demerits	-	132	66	49	32	40	24	-	188	-	52	72
Total Demerits		172	92	60	40	47	50		213		64	85
Fuel Type	90/10	85/15	85/15	85/15/DME	85/15/DME	85/15/DME	85/15	85/15	85/15/DME	85/15/DME	85/15/DME	85/15/DME
Modifications	NO	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cars	335	343	329 330 331 344	333 336 339	337 338	338	330	331 339 342 343 344	333* 335 336	337	338 339	338

* Upon examination, these three cars had either disconnected vacuum lines or dirty carburetors.

Table 19/ Test Results at Approximately -6°C

	Jan. 17/85 at -6°C		Jan. 18/85 at -6°C	
Time to First Fire, s	1.2	1.0	1	1
Time to Start, s	5.6	6.5	7	6
Idle Quality Demerits	16	8	37	24
Drive Accel. Demerits	-	-	6	8
Road Load Demerits	-	-	2	0
Driveability Demerits	-	-	45	32
Total Demerits	-	-	52	38
Fuel Type	85/15/DME	85/15/DME	85/15/DME	85/15/DME
Modifications	Yes	Yes	Yes	Yes
Cars	All 10	338	All 10	338

The performance on the best fuel, 85/15/DME, with the latest modifications developed by Ford, gives marginally acceptable performance down to the -15°C temperature range.

Comparing the various results with car 338, which operated on the same fuel, 85/15/DME with all modifications, for four days, shows that as the temperature dropped 9°C over the range from -6 to -15°C, demerits increased 23%/°C overall and 16%/°C on start only.

Previous late-model gasoline-powered test fleets at ORC have shown an increase of 11%/°C over the range of +5 to -10°C, using the ORC driveability procedure.

The areas where the methanol-fuelled vehicles are poorer are in cold-start time and malfunctions in the drive acceleration portion of the test, specifically, hesitation and stalling.

These Ford Escorts, when operated on the 85/15/DME blend with all the proper modifications, give marginally acceptable cold weather performance. However, it must be noted that all the cars were exceptionally well tuned and the fuel was not weathered. Additionally, to ensure cold starts, particularly below -14°C, either a new or larger-than-normal battery is required.

3.10/ Cold Weather Operation -- April Program

Further to the work performed in January, testing of two Ford Escorts fuelled with near-neat methanol fuel was continued until early April.

Two of the Ford Escorts, cars 336 and 337, were selected for further testing, using the modified ORC driveability procedure. This procedure has been used in previous tests with these cars. The modification to the procedure was to include a 30 s idle immediately after start-up and to not include the start in the driveability demerit rating.

Tests were performed both on the ORC test track and at Kapuskasing in Northern Ontario. The cars were set up as per the hardware changes developed in the January trial.

Three test fuels were blended:

1/ MA -- 85.6% by mass methanol and 14.2% by mass SNL-W;
2/ MB -- with additional n-butane, giving 79.1% by mass methanol, 13.9% by mass SNL-W, and 7.0% by mass n-butane; and
3/ MC -- the MA blend with additional DME, giving a blend of 79.1% by mass methanol, 13.9% by mass SNL-W, and 7.0% by mass DME.

Table 20/ Test Fuel Blends -- April 1985

	MA		MB		MC	
COMPONENTS	% by Vol.	% by Mass	% by Vol.	% by Mass	% by Vol.	% by Mass
Methanol (MeOH)	85.0	85.6	76.4	79.1	77.2	79.1
Super Non-Leaded Gasoline -- Winter Grade (SNL-W)	15.0	14.2	14.3	13.9	14.5	13.9
n-Butane	-	-	9.3	7.0	-	-
Dimethylether (DME)	-	-	-	-	8.3	7.0
INSPECTION PROPERTIES						
Density, kg/L	0.786		0.768		0.781	
RVP (Dry), kPa (psi)	62.6	(9.1)	149.2	(21.6)	121.2	(17.6)
ASTM D-86 Distillation:						
IBP, °C		59		32		38
10%, Evap., °C		61		32		38
50%, Evap., °C		64		64		64
90%, Evap., °C		64		65		65
EP, °C		66		77		78
% Recovery		98.0		92.3		93.0
Carbon		43.9		46.4		45.2
Hydrogen		12.5		13.0		12.9
Oxygen		43.6		40.6		41.9
Water Content, ppm		132		-		-
Stoichiometric Air/Fuel Ratio by Mass		7.6:1		8.2:1		7.7:1
Latent Heat of Evap. at 0°C, MJ/L	0.908		0.840		0.853	

Table 20 gives inspection properties of the three test fuels.

The dry RVPs of the three blends were 62.6 kPa (9.1 psi), 149.2 kPa (21.6 psi), and 121.2 kPa (17.6 psi), respectively. The last two values are in excess of that allowable for winter-grade gasoline.

The objective behind the selection of these three test fuels was to
- evaluate the hardware modifications using the ORC driveability procedure and
- compare the use of n-butane and DME as priming agents.

Various inspection properties of the four blending components -- methanol, SNL-W, n-butane, and DME -- are given in Table 21. DME is more volatile than n-butane, having a lower boiling point and a higher RVP. However, the latent heat of evaporation for DME is one-third higher than that of n-butane.

The results of the driveability testing are given in Table 22 and shown graphically in Figure 9. All results given are an average of tests done on the two test cars. The ambient temperature ranged from approximately +6°C to -15°C. Fuel MC gave the best results, namely, nine demerits at +5°C and 41 at -10°C.

The results from the 1984 test program [2] can be compared to the results given in Table 22. In 1984, on the original fuel specification of 90.6% by mass methanol and 9.4% by mass SNL-W, levels of 107 demerits at +5°C and 315 at -10°C were obtained. The best fuel tested at that time, namely, 85.5% by mass methanol, 8.9% by mass SNL-W, and 5.6% by mass DME, gave 53 demerits at +5°C and 148 at -10°C. These tests were performed using the modified ORC driveability procedure.

These data indicate that the hardware modifications, as defined in the January trial, have significantly improved the cold weather driveability of these cars. The fuel modifications (increasing the amount of primer in the blend) have also caused substantial improvements in the cold weather performance.

To allow a more valid comparison with tests performed on late-model gasoline-powered cars at ORC, a limited number of tests were performed without modifying the ORC driveability procedure. These are shown in Table 22. Typical results with late-model gasoline-powered cars would be 20 to 30 demerits at +5°C and 35 to 50 at -10°C, on winter-grade gasolines.

Table 21/ Base Component Properties

INSPECTION PROPERTIES	Methanol	SNL-W [1]	n-Butane	DME [2]
Density, kg/L	0.796	0.742	0.579	0.661
RVP (Dry), kPa (psi)	30.2(4.4)	94.2(13.7)	356(52)	850(123)
ASTM D-86 Distillation:				
IBP, °C	64	28	-0.5	-25
10%, Evap., °C	64	41	-	-
50%, Evap., °C	64	105	-	-
90%, Evap., °C	64	154	-	-
EP, °C	67	198	-0.5	-25
% Recovery	99.8	94.3	-	-
Carbon, % by Mass	37.7	86.6	82.8	52.1
Hydrogen, % by Mass	12.6	13.4	17.6	13.0
Oxygen, % by Mass	49.7	-	-	34.9
Water Content, ppm	425	125	-	-
Estimated Vapour Press at 0°C, kPa	0.2	2	7	25
Auto-Ignition Temp., °C	470	410	405	350
Latent Heat of Evap. at 0°C, MJ/L	0.996	0.408	0.223	0.300
Stoichiometric Air/Fuel Ratio, Mass	6.4:1	14.6:1	15.4:1	9.0:1
Flammability Ranges, Vol. % in Air	7-44	1-8	2-8	4-27

[1] SNL-W -- super non-leaded -- winter grade
[2] DME -- dimethylether

Table 22/ Driveability Test Results

FUEL	MA		MB		MC	
	Test Temp., °C	Driv. Demerits	Test Temp., °C	Driv. Demerits	Test Temp., °C	Driv. Demerits
Test Results (Each Result the Average of Tests on Two Vehicles)	+5	15	+5.5	3	+6	3
	+5	8	+4	2	+4	5
	-3.5	42	-3	48	-3	34
	-8.5	67	-8.5	37	-5	39
					-15.5	46
Regression Equations	DD = -4.0(temp.) +31.0		DD = -3.1(temp.) +21.0		DD = -2.2(temp.) +19.5	
R^2 Value	0.983		0.720		0.853	
Estimated DD Levels	+5	11	+5	5	+5	9
	-10	71	-10	52	-10	41
Test Results with No 30 s Idle After Start-up (Average of Two Vehicle Tests)	+5.5	100	-	-	+6	18

NOTE: DD = driveability demerits
Temp. = ambient temperature, °C
R = correlation coefficient

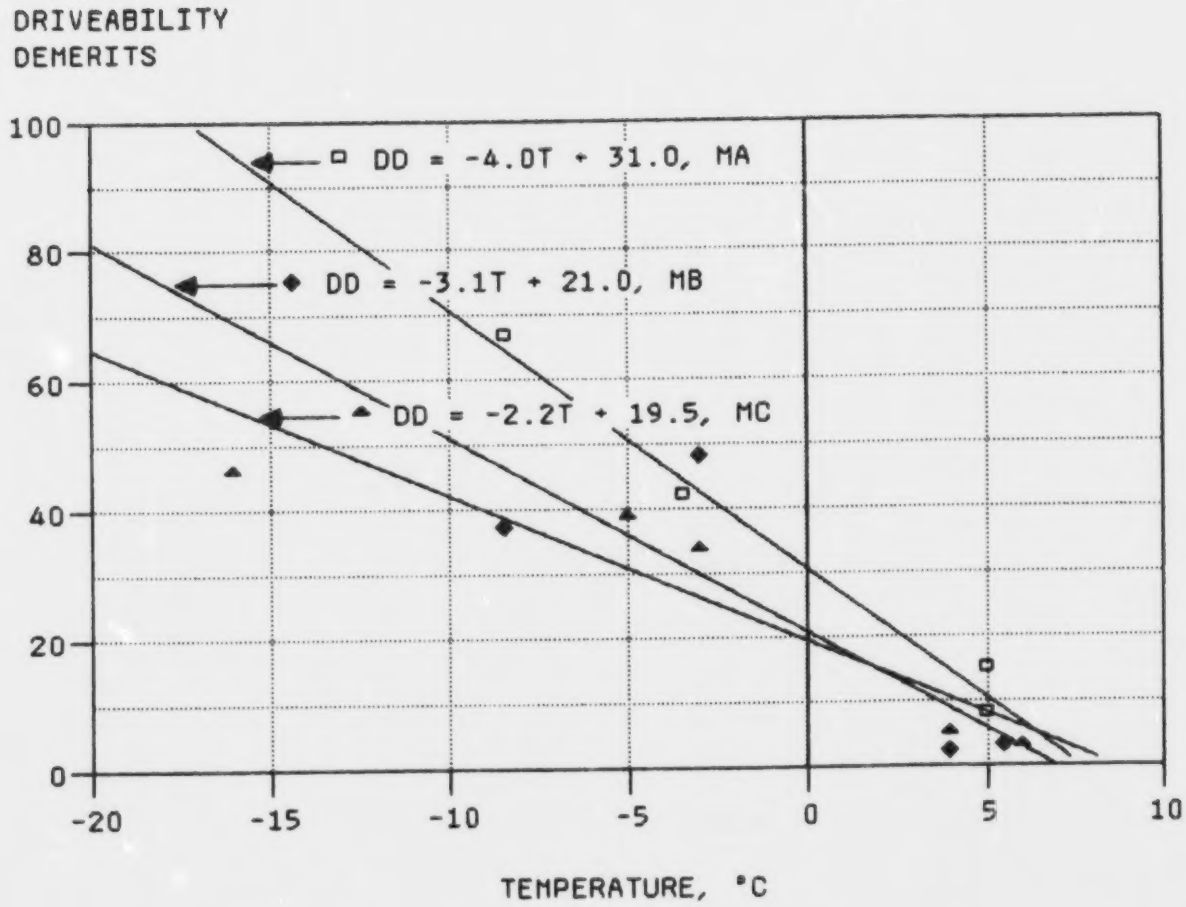


Figure 9/ Driveability Performance of the Three Test Fuels (Cars 336 and 339)

The unmodified results on fuel MA were 100 demerits at +6°C (versus nine with the modified procedure) and on fuel MC, 18 demerits at +6°C (versus six with the modified procedure). This indicates that the cold weather driveability performance of these cars is still marginal when compared to gasoline, even with the latest modifications and when operated on the best fuel, namely, MC.

Comparing the results with fuels MB and MC shows that the use of n-butane instead of DME is detrimental to cold weather performance. The driveability performance at temperatures above 0°C is roughly equivalent for these two blends; at lower ambients, fuel MC gives better performance.

The results with fuel MB were not as consistent as the other two test fuels, as shown by the lower value of R^2 (R being the correlation coefficient), namely, 0.720. The reasons for these larger variations are not that apparent.

Table 23 gives the startability results with the three test fuels. Figure 10 shows the results graphically. The three fuels are equivalent at +15°C and above. Fuels MB and MC are equivalent at lower ambients, down to -10°C. At temperatures below -10°C, only fuel MC was tested, giving 7.5 s starts at -15.5°C. This is exceptional performance for a near-neat methanol-fuelled car and in the acceptable range for a gasoline-powered car.

Based on the inspection properties (Table 2C), fuel MB, with its lower latent heat of evaporation, higher RVP, and higher stoichiometric air/fuel ratio (meaning the car will operate richer) compared to fuel MC, should give better cold weather performance than fuel MC.

The reason for MB's poorer performance may be related to either the actual vapour pressure at the ambient test temperatures being higher for blend MC or the level of ignition energy required for proper flame propagation being lower with MC than MB.

Further work, possibly more fundamental in nature, would be required to discern the difference between the use of a light hydrocarbon or light ether as a priming agent for near-neat methanol fuel.

To conclude, the vehicle modifications, combined with blend MB or MC, give cold weather performance that is marginal when compared to that of late-model gasoline-fuelled cars. However, it should be noted that the best two fuels had RVP levels much higher than that allowed for winter-grade gasolines. Reducing the RVP to that allowable for winter gasolines would impair the cold weather performance somewhat.

Table 23/ Startability Test Results

FUEL	MA		MB		MC	
	Test Temp., °C	Time to Start, s	Test Temp., °C	Time to Start, s	Test Temp., °C	Time to Start, s
Test Results (Each Result the Average of Tests on Two Vehicles)	5.5	1.5	5.5	1.5	6.0	0.75
	5.0	0.5	4.0	1.5	6.0	1.0
	5.0	0.75	-6.5	5.0	4.0	1.0
	-10.0	15.5	-9.5	3.0	-3.0	4.5
					-5.0	3.5
					-15.5	7.5
Regression Equations	t = -0.96(temp.) +5.88		t = -0.17(temp.) +2.47		t = -0.31(temp.) +2.65	
R^2 Value	0.992		0.601		0.957	
Estimated Time to Start, s	5.0	1.1	5.0	1.6	5.0	1.1
	-10.0	15.5	-10.0	4.2	-10.0	5.8
	-20.0	25.1	(-20.0	5.9)	-20.0	8.9

NOTE: t = time to start, s
Temp. = temperature, °C
R = correlation coefficient

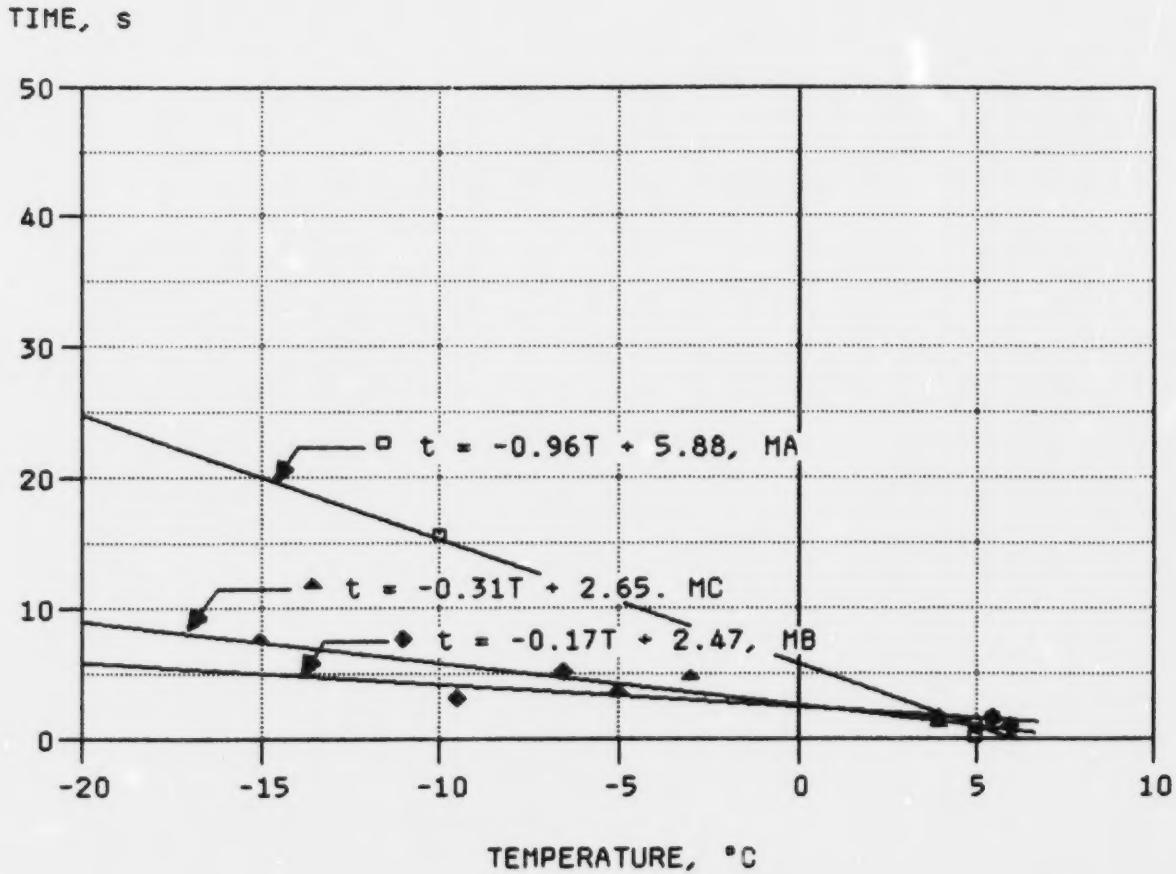


Figure 10/ Startability Performance of the Three Test Fuels (Cars 336 and 339)

3.11/ Exhaust Emissions

The exhaust emissions were measured on two of the cars, numbers 339 and 340, at +25°C, as per Transport Canada (TC) methods. Table 24 details these results, taken at a nominal distance accumulation of 30 000, as well as results from the prior phases of this program [2].

The fuel used was blend 11 or M85-85% by volume methanol and 15% by volume super non-leaded gasoline. Inspection properties of the blend are given in Table 2.

The exhaust emission testing on these two cars was performed after recalibration in January 1985, as described in Section 3.9.

Both this recalibration and the change in fuel would be expected to alter the emission results slightly. However, the increase in distance accumulation would tend to mask both of these effects.

Since initial testing at 1000 km, on a M90 blend with 5% by mass added DME, both unburnt hydrocarbons and oxides of nitrogen increased to approximately 1.7 times their original level. Carbon monoxide increased to approximately 2.5 times its original level.

The unburnt hydrocarbon emissions include methane, as the equipment used cannot measure to the Californian non-methane standard. Therefore, the actual non-methane hydrocarbon emissions would be less than the reported values.

The increases in emissions with these two particular cars are higher than would be expected with similar gasoline-powered cars. At the most recent test increment, the cars did not meet any of the Californian standards to which they were built; however, they still meet 1983 Canadian emission standards. Results from the cars in California indicate that the increase in emissions is lower for these cars than with similar gasoline-fuelled cars [10,11].

These two cars have been recalibrated, operated in a much colder climate than those in California, and possibly in a different type of service. These three factors, particularly the first, probably account for the change in exhaust emission performance.

3.12/ Fuel Consumption

Fuel consumptions were measured in association with the exhaust emission testing and also at 60 and 100 km/h on the chassis dynamometer. These

Table 24/ Exhaust Emission Results

Nominal km	Blend Type	Car No.	Test Temp., °C	City Cycle Emissions, g/km HC	CO	NO_x	
30 000	M85	339	+25	0.55	5.58	0.51	
30 000		340	+25	0.37	5.01	0.44	
30 000		Average	+25	0.46	5.30	0.47	Row 1
20 000	M90+ 5DME	339 [1]	+25	0.61	4.05	0.35	
26 000		340 [2]	+25	0.59	6.69	0.40	
23 000		Average	+25	0.60	5.37	0.38	Row 2
1 000	M90+ 5DME	339	+25	0.28	2.65	0.29	
1 000		340	+25	0.25	1.59	0.27	
1 000		Average	+25	0.27	2.12	0.28	Row 3
1983 Canadian Std. for Gasoline-Powered Cars			+25	1.2	15.5	1.9	
1983 Californian Std. for Gasoline-Powered Cars			+25	0.24 [3]	4.3	0.43	

[1] Average of duplicate runs
[2] New catalyst installed prior to test
[3] Non-methane standard
Underlined values exceed Californian Std.

Table 25/ Dynamometer Fuel Consumption Results

Nominal km	Blend Type	Car No.	Fuel Consumption L/100 km Urban Rating	Highway Rating	Combined Rating	Steady State 60 km/h	100 km/h	
30 000	M85	339	16.48	9.86	13.50	7.71	10.79	
30 000	M85	340	15.99	9.59	13.11	7.84	10.48	
30 000		Average	16.24	9.73	13.31	7.78	10.64	Row 1
21 000	M90+ 5DME	339[1]	15.93	10.79	13.62	8.38	11.11	
26 000	M90+ 5DME	340[2]	14.55	9.78	12.40	7.59	10.50	
23 000		Average[3]	15.24	10.29	13.01	7.99	10.81	Row 2
1 000	M90+ 5DME	339	14.93	10.49	12.93	7.26	11.42	
1 000	M90+ 5DME	340	15.96	10.26	13.25	7.89	11.29	
1 000		Average	15.31	10.38	13.09	7.58	11.36	Row 3
$\frac{\text{Row 3 - Row 1}}{\text{Row 1}} \times 100$, %[4]			-5.7	+6.7	-1.7	-2.6	+6.8	
$\frac{\text{Row 2 - Row 1}}{\text{Row 1}} \times 100$, %[4]			-6.2	+5.8	-2.3	+2.7	+1.6	

[1] Average of 2 runs on 339
[2] Average of 3 runs on 340
[3] Average of two averages above
[4] A positive value indicates that the fuel consumption has dropped; a negative value indicates fuel consumption has increased.

results (Appendix F), along with prior results with the two test cars, numbers 339 and 340, are given in Table 25.

Again, as noted in Section 3.11, two changes occurred with these cars, apart from the increase in distance travelled: recalibration and a change in the fuel used from M90 plus 5% by mass DME to M85.

M85 has approximately 4% more energy content than M90 + 5DME (18.3 MJ/L versus 17.5 MJ/L). The dynamometer runs with a warmed-up engine, namely, the highway rating and the steady-state tests, do show a drop in fuel consumption of between 1.6 and 5.8%, with an average of 3.4% between the last two tests at 23 000 and 30 000 km, respectively. This could be attributed to the fuel change.

The changes in calibration concerned mainly cold starting, the enrichment of the choke being a major part. The results for the urban rating fuel consumption increased by approximately 6% between the last two tests. Indications were that this is caused by the richer operation during the transient cold portion and, especially, the stabilized cold portion of the driving cycle.

The average energy consumption of these two vehicles can be calculated. A combined rating of 13.31 L/100 km equates to an energy consumption of 244 MJ/100 km. Results of Transport Canada testing of an equivalent gasoline-powered 1983 Ford Escort were 7.5 L/100 km or 242 MJ/100 km, with a gasoline energy content of 32.2 MJ/L.

The recalibration of these Ford Escorts, combined with the use of M85, has resulted in an energy consumption approximately equivalent to the gasoline version.

4/ CONCLUSIONS

1/ All three test oils gave low sludge, varnish, and valve deposits.

2/ Engine measurements and used-oil analysis indicate that both cam and ring wear occurred with these cars.

3/ All of the three oils performed acceptably in this short-trip cold-engine driving test.

4/ Energy consumption of these cars was approximately equal to equivalent gasoline-powered cars under both summer ambient conditions (i.e., +25°C) and when tested according to Transport Canada methods.

5/ Energy consumption during winter increased by approximately 25% over the summer value.

6/ These cars gave poorer cold weather performance than would be expected with equivalent gasoline cars. The original engine calibration was developed for the mild climate of California.

7/ No maintenance problems caused by the use of near-neat methanol fuel occurred.

8/ The cold weather performance of these cars has been improved by various hardware changes.

9/ The cold weather performance can be further improved by the use of very volatile test fuels.

10/ The exhaust emissions of the two cars tested were higher than expected. This was probably due to recalibration, duty cycle, and colder ambient conditions in Canada.

5/ RECOMMENDATIONS

1/ Further testing is required to differentiate between the three test oils. This is being addressed by a longer term (Phase 4) engine durability trial now under way.

2/ A further long-term test is required to ensure that engine life and exhaust emissions would not be impaired with the use of methanol as a fuel in cold climates.

3/ The cold weather performance must be improved by hardware modifications, as little latitude is left in possible fuel modifications.

4/ Improvements in the energy consumption must occur if methanol is to be a competitive fuel.

6/ REFERENCES

[1] Mitchell, D.K., "Straight Methanol and Vehicle Evaluation - Phase 1, The Cold Weather Performance of a Variety of Methanol Fuel Blends," AF-84-03, Transportation Energy Management Program, Downsview, Ontario, Canada, April 1984.

[2] Mitchell, D.K., "Straight Methanol and Vehicle Evaluation - Phase 2, Durability of a Fleet of Methanol-Fuelled Vehicles," AF-85-03, Transportation Energy Management Program, Downsview, Ontario, Canada, August 1985.

[3] Chaibongsai, S., et al, "Development of an Engine Screening Test to Study the Effect of Methanol Fuel on Crankcase Oils," Society of Automotive Engineers Paper 830240, Warrendale, Pa., USA, 1983.

[4] Chamberlin, W.B., and Brandow, W.C., "Lubrication Experience in Methanol-Fuelled Engines under Short-Trip Service Conditions," Society of Automotive Engineers Paper 831701, Warrendale, Pa., USA, 1983.

[5] Ryan, T.W., III, et al, "The Mechanisms Leading to Increased Cylinder Bore and Ringwear in Methanol-Fueled S.I. Engines," Society of Automotive Engineers, Paper 811200, Warrendale, Pa., USA, 1981.

[6] Marbach, H.W., et al, "The Effects of Lubricant Composition on S.I. Engine Wear with Alcohol Fuels," Society of Automotive Engineers, Paper 831702, Warrendale, Pa., USA, 1983.

[7] Krumm, H., et al, "Lubrication of Spark Ignition Engines Running on Alcohol Containing Fuels," 5th International Symposium on Alcohol Fuels, Auckland, New Zealand, May 1982.

[8] "Fuel Consumption Guide," Transport Canada Road Safety Branch, 1983 Edition.

[9] West Germany Ministry of Research and Technology, "Demonstration and Research Program: Alternative Fuels for Road Transportation," 1979.

[10] Nichols, R.J., and Norbeck, J.M., "Assessment of Emissions from Methanol-Fueled Vehicles: Implications for Ozone Air Quality," 78th Annual Meeting of Air Pollution Control Association, Detroit, Michigan, June 1985.

[11] Nichols, R.J., "Field Experience with Methanol Vehicles: Future Design Considerations," Co-ordinating European Council, Wolfsburg, Germany, June 1985.

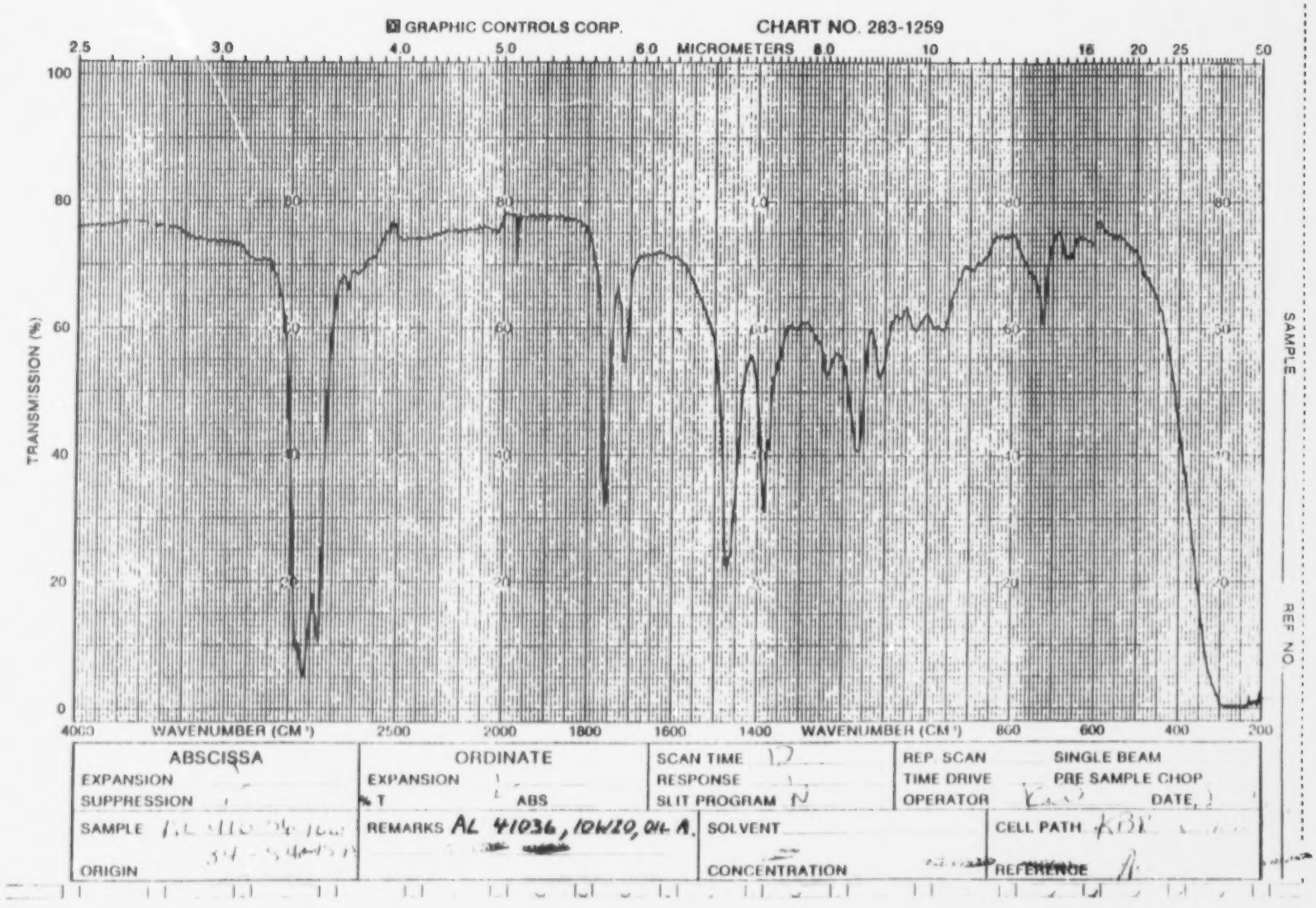
APPENDIX A/ TEST CAR IDENTIFICATION

APPENDIX A/ TEST CAR IDENTIFICATION

Test Car No.	License Plate No.	Colour	VIN
336	VAB 236	Yellow	1FABP1475DS243331
337	VAB 237	White	1FABP1473DW243327
338	VAB 238	Black	1FABP1471DW243326
339	VAB 239	Dk. Blue	1FABP1477DW243332
340	VAB 240	Pewter	1FABP1475DW243328
341	XZD 569	Red	2FABP1340DX126834

All cars were 4-door hatchback configuration.

APPENDIX B/ NEW OIL INFRARED SCANS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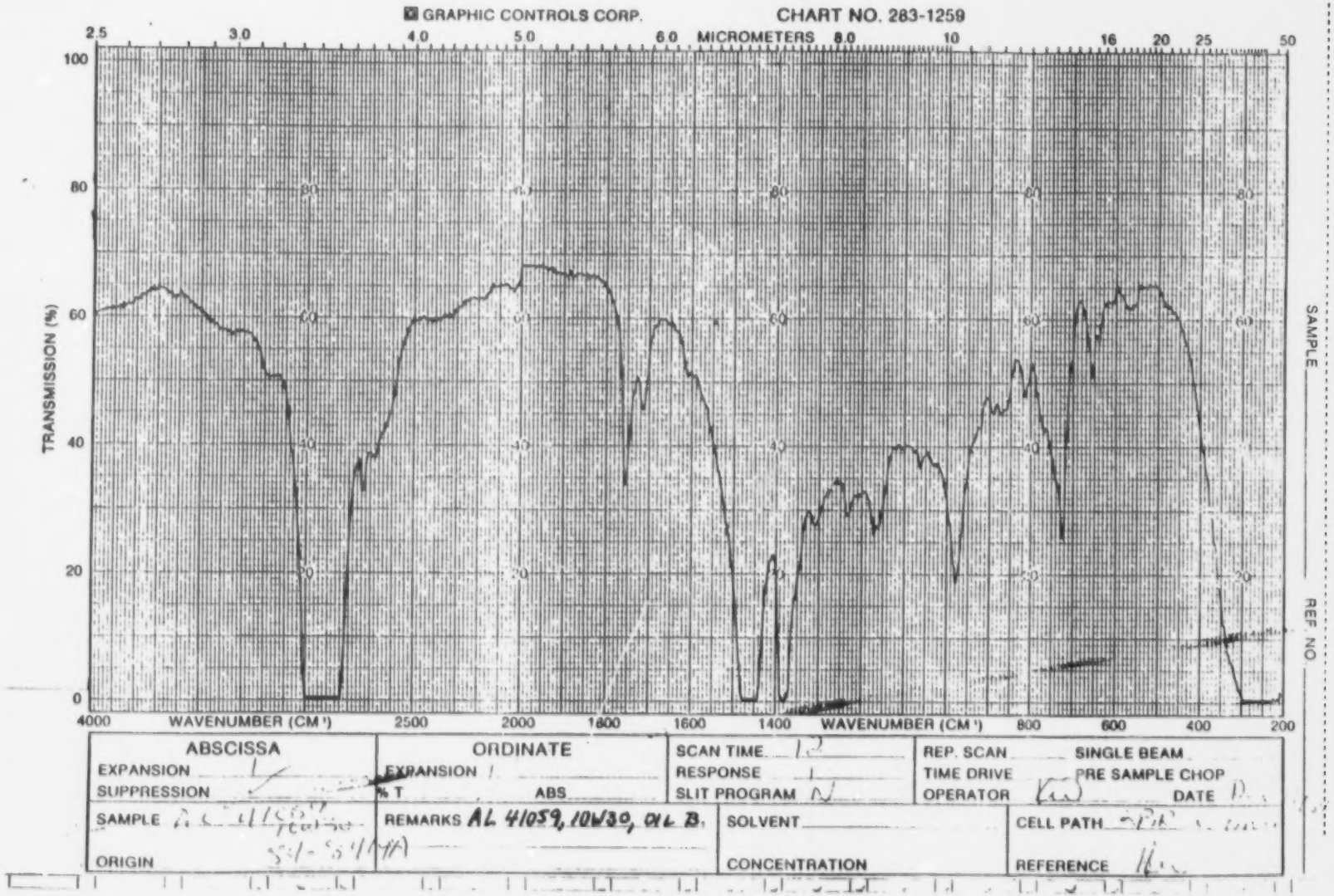
2.5 3.0 4.0 5.0 6.0 MICROMETERS 8.0 10 15 20 25 50
100 80 60 40 20 0
TRANSMISSION (%)
4000 WAVENUMBER (CM⁻¹) 2500 2000 1800 1600 1400 WAVENUMBER (CM⁻¹) 800 600 400 200
SAMPLE
REF NO.
ABSCISSA
EXPANSION
SUPPRESSION
ORDINATE
EXPANSION
%T ABS
SCAN TIME 12
RESPONSE
SLIT PROGRAM N
REP. SCAN SINGLE BEAM
TIME DRIVE PRE SAMPLE CHOP
OPERATOR DATE
SAMPLE
ORIGIN
REMARKS AL 41036, 10W20, 04 A.
SOLVENT
CONCENTRATION
CELL PATH KBr
REFERENCE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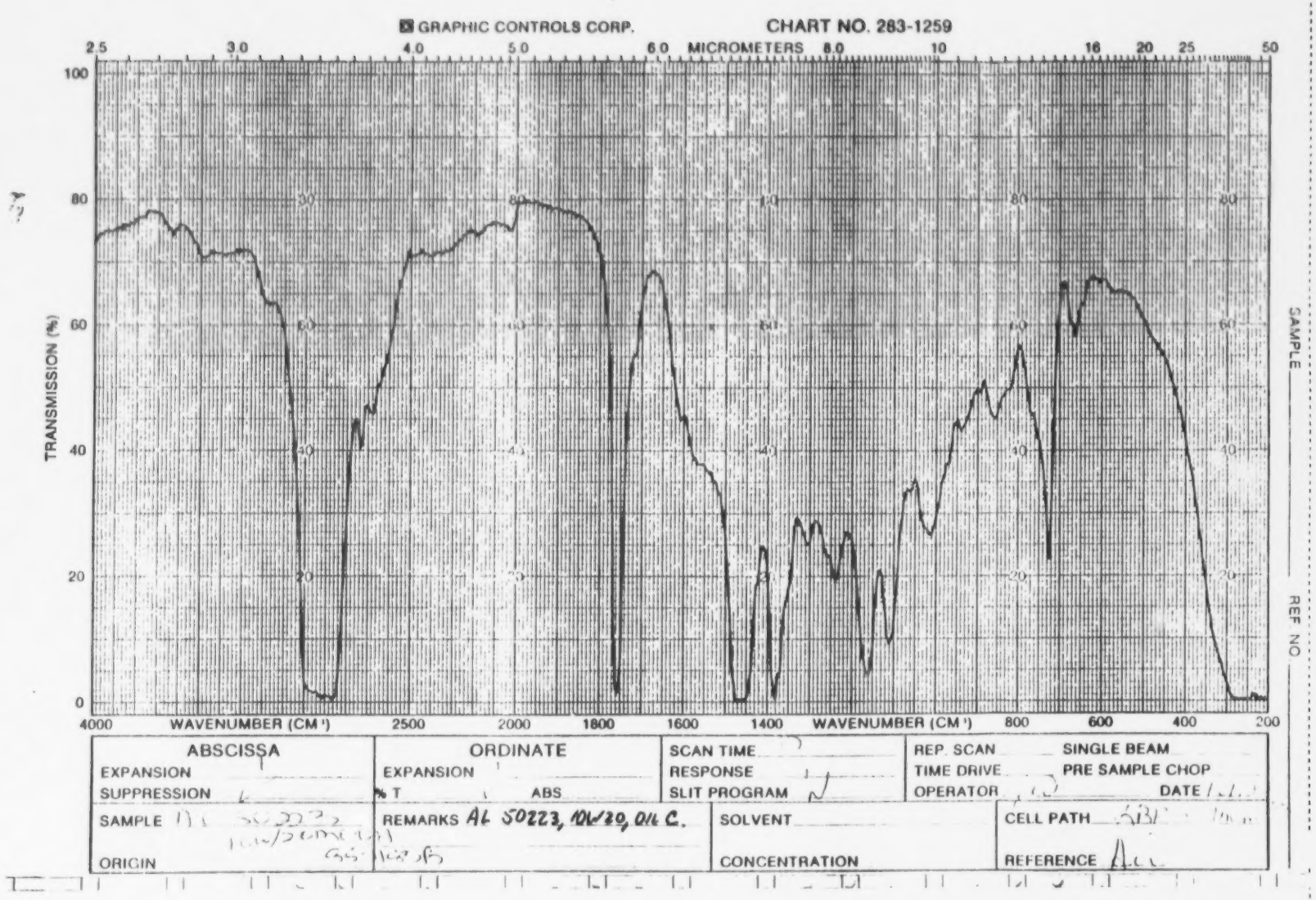
100 80 60 40 20 0
TRANSMISSION (%)
4000 WAVENUMBER (CM⁻¹) 2500 2000 1800 1600 1400 WAVENUMBER (CM⁻¹) 800 600 400 200
SAMPLE
REF. NO
ABSCISSA
EXPANSION 1
SUPPRESSION
ORDINATE
EXPANSION 1
% T ABS
SCAN TIME 12
RESPONSE 1
SLIT PROGRAM N
REP. SCAN SINGLE BEAM
TIME DRIVE PRE SAMPLE CHOP
OPERATOR KW DATE D.
SAMPLE
ORIGIN
REMARKS AL 41059, 10W30, OIL B.
SOLVENT
CONCENTRATION
CELL PATH
REFERENCE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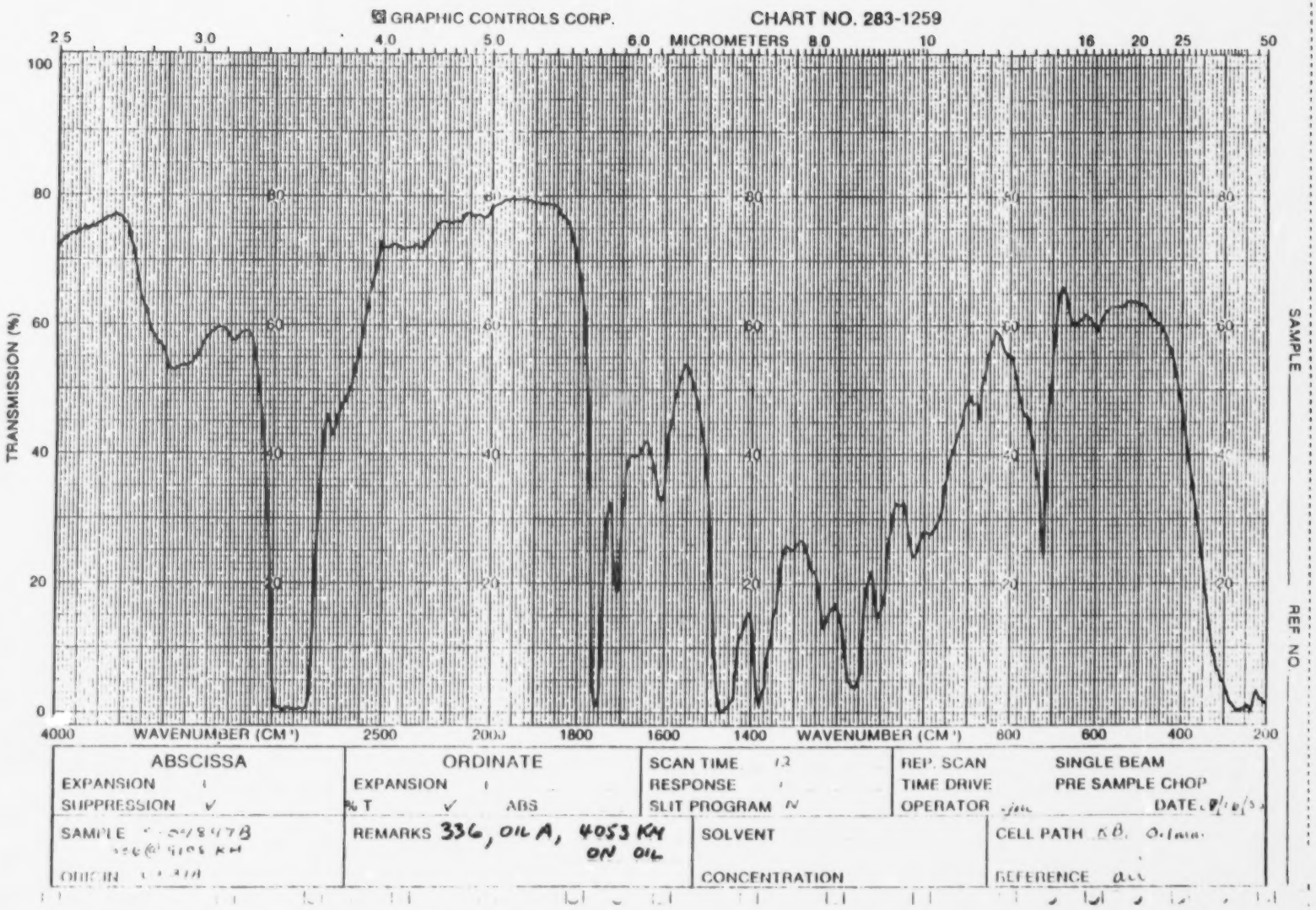
100 80 60 40 20 0
TRANSMISSION (%)
4000 WAVENUMBER (CM⁻¹) 2500 2000 1800 1600 1400 WAVENUMBER (CM⁻¹) 800 600 400 200
SAMPLE
REF NO
ABSCISSA
EXPANSION
SUPPRESSION
ORDINATE
EXPANSION
% T ABS
SCAN TIME
RESPONSE
SLIT PROGRAM
REP. SCAN
TIME DRIVE
OPERATOR
SINGLE BEAM
PRE SAMPLE CHOP
DATE
SAMPLE
REMARKS AL 50223, 10L20, 014 C.
SOLVENT
CELL PATH
ORIGIN
CONCENTRATION
REFERENCE

APPENDIX C/ SELECTED USED-OIL INFRARED SCANS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4000 WAVENUMBER (CM⁻¹) 2500 2000 1800 1600 1400 WAVENUMBER (CM⁻¹) 800 600 400 200
SAMPLE
REF. NO.
ABSCISSA
EXPANSION
SUPPRESSION ✓
ORDINATE
EXPANSION
% T ✓ ABS
SCAN TIME 12
RESPONSE
SLIT PROGRAM N
REP. SCAN
TIME DRIVE
OPERATOR
SINGLE BEAM
PRE SAMPLE CHOP
DATE
SAMPLE
REMARKS 336, OIL A, 4053 KM ON OIL
SOLVENT
CONCENTRATION
CELL PATH
REFERENCE

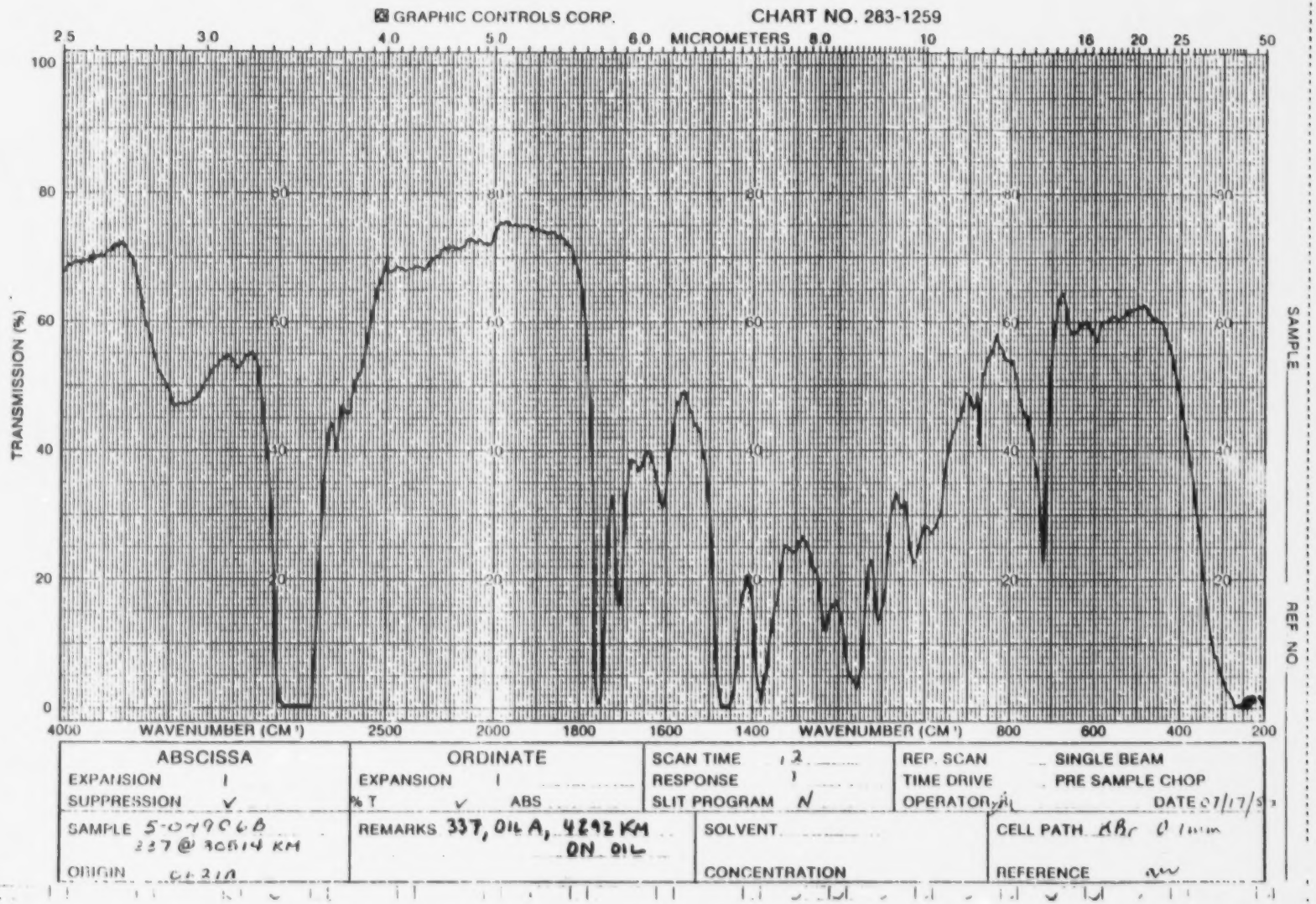
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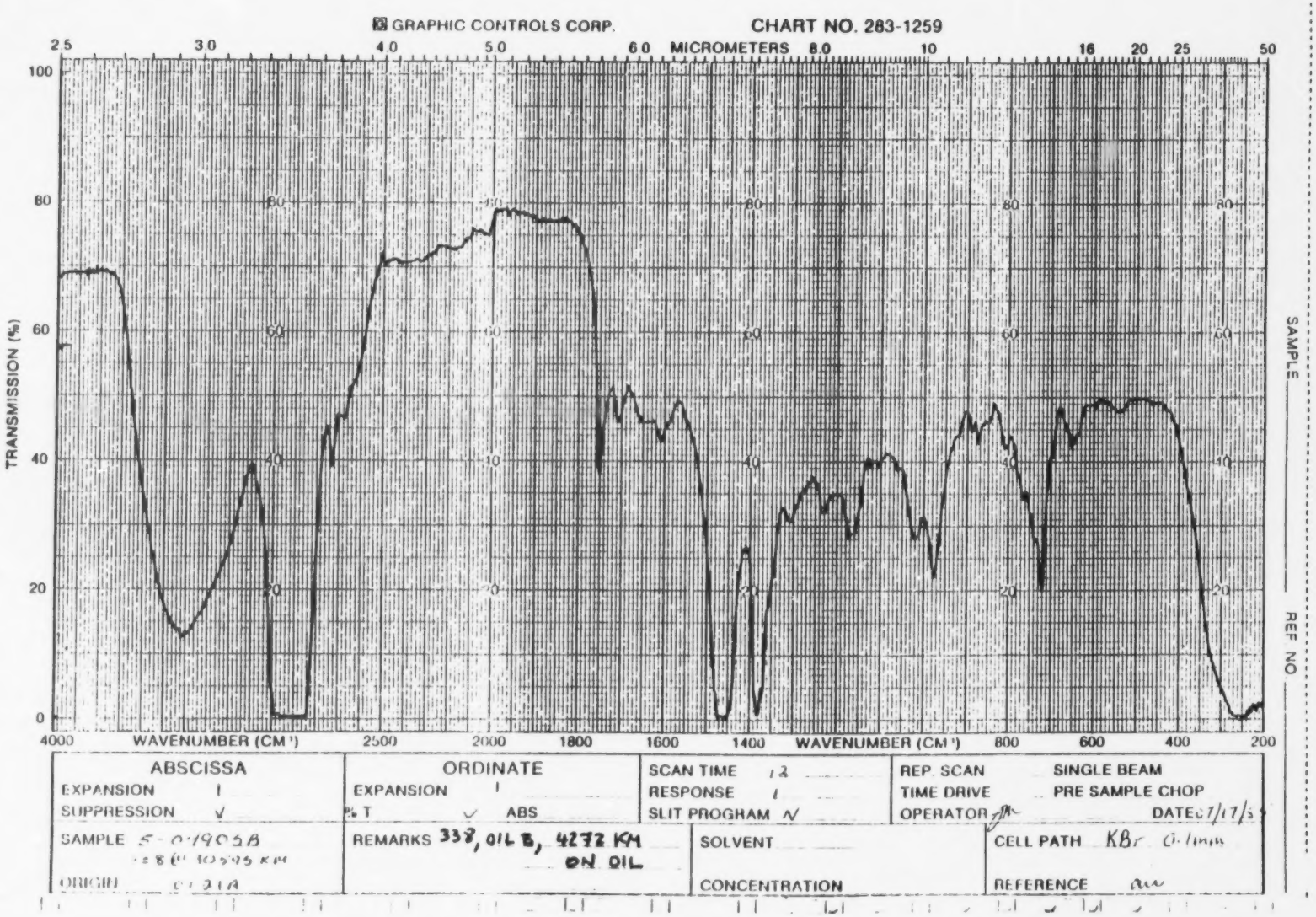
CHART NO. 283-1259
MICROMETERS
TRANSMISSION (%)
WAVENUMBER (CM⁻¹)
WAVENUMBER (CM⁻¹)
SAMPLE
REF NO
ABSCISSA
EXPANSION 1
SUPPRESSION V
ORDINATE
EXPANSION 1
% T V ABS
SCAN TIME 2
RESPONSE 1
SLIT PROGRAM N
REP. SCAN SINGLE BEAM
TIME DRIVE PRE SAMPLE CHOP
OPERATOR
DATE 07/17/
SAMPLE 5-079066B
237 @ 30614 KM
ORIGIN
REMARKS 337, 014 A, 4292 KM
ON OIL
SOLVENT
CONCENTRATION
CELL PATH CBr 0 1mm
REFERENCE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TRANSMISSION (%)
4000 WAVENUMBER (CM⁻¹) 2500 2000 1800 1600 1400 WAVENUMBER (CM⁻¹) 800 600 400 200
SAMPLE
REF NO
ABSCISSA
EXPANSION 1
SUPPRESSION √
ORDINATE
EXPANSION 1
% T √ ABS
SCAN TIME 12
RESPONSE 1
SLIT PROGRAM N
REP. SCAN SINGLE BEAM
TIME DRIVE PRE SAMPLE CHOP
OPERATOR
DATE 7/17/3
SAMPLE S-0190SB
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SOLVENT
CONCENTRATION
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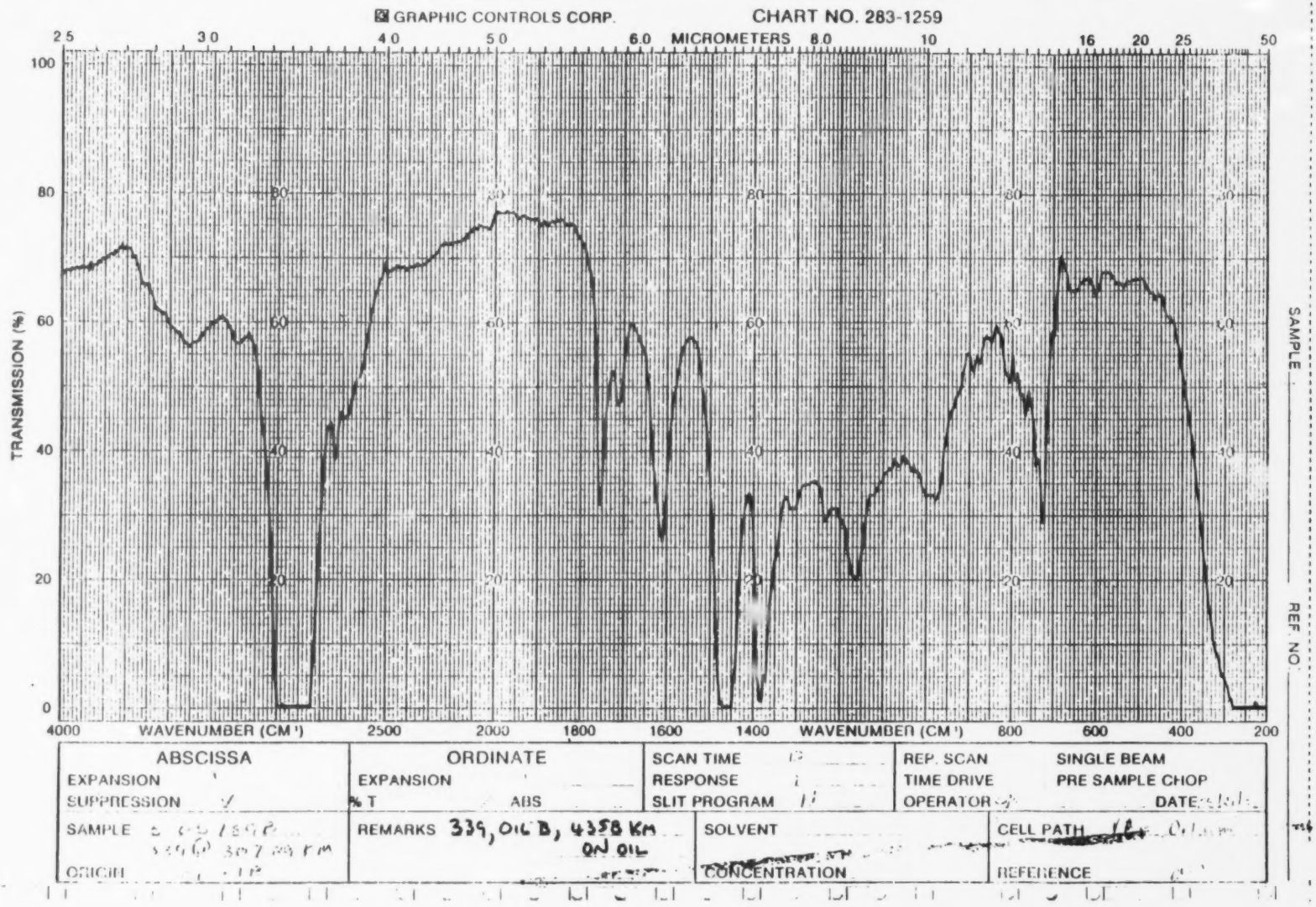
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TRANSMISSION (%)
4000 WAVENUMBER (CM⁻¹) 2500 2000 1800 1600 1400 WAVENUMBER (CM⁻¹) 800 600 400 200
SAMPLE
REF. NO.
ABSCISSA
EXPANSION
SUPPRESSION
ORDINATE
EXPANSION
% T ABS
SCAN TIME
RESPONSE
SLIT PROGRAM
REP. SCAN SINGLE BEAM
TIME DRIVE PRE SAMPLE CHOP
OPERATOR DATE
SAMPLE
ORIGIN
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CONCENTRATION
CELL PATH
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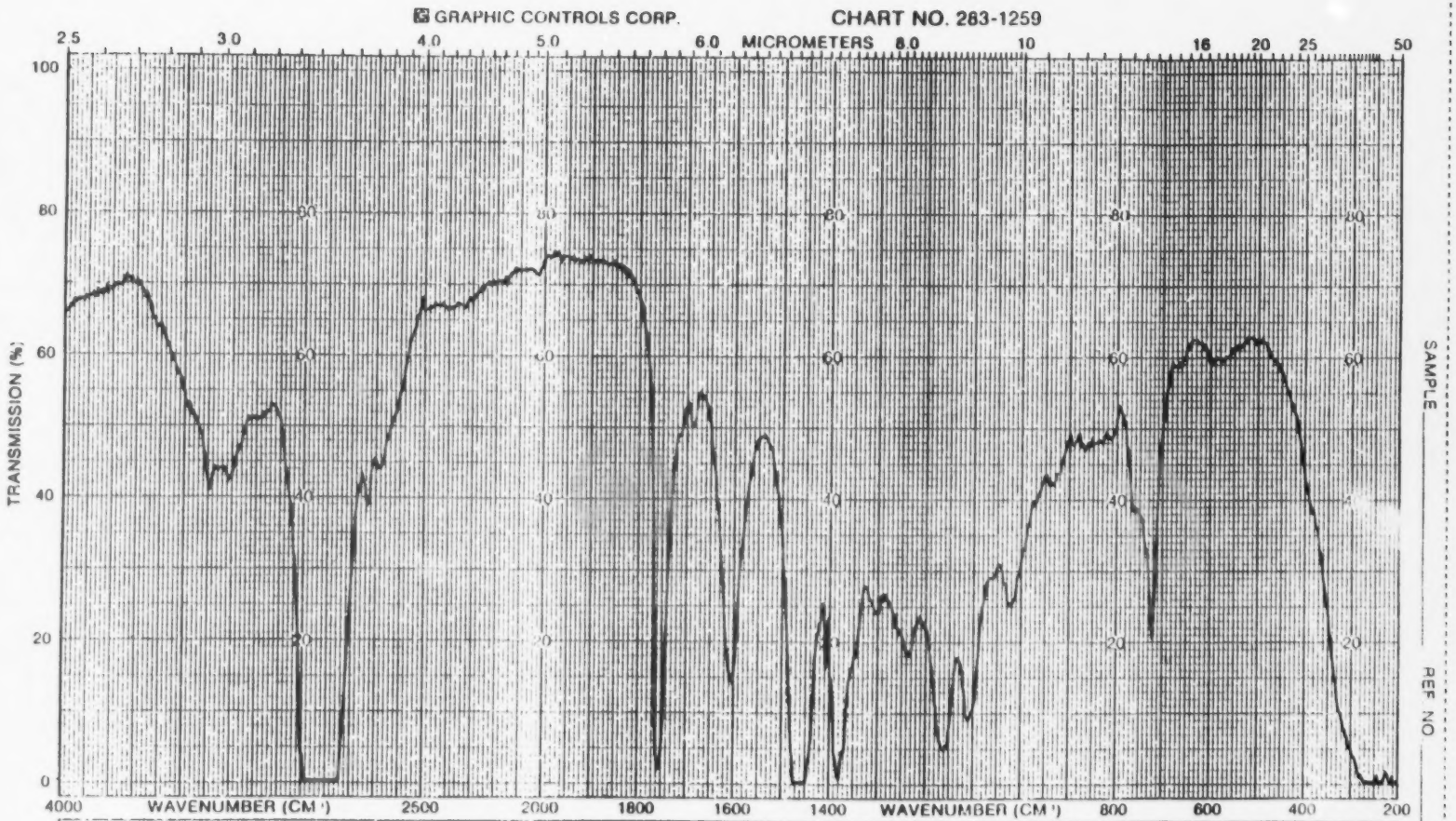
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TRANSMISSION (%)
4000 WAVENUMBER (CM⁻¹) 2500 2000 1800 1600 1400 WAVENUMBER (CM⁻¹) 800 600 400 200
SAMPLE
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ABSCISSA
EXPANSION 1
SUPPRESSION
ORDINATE
EXPANSION
% T ABS
SCAN TIME
RESPONSE
SLIT PROGRAM M
REP. SCAN SINGLE BEAM
TIME DRIVE PRE SAMPLE CHOP
OPERATOR
DATE
SAMPLE
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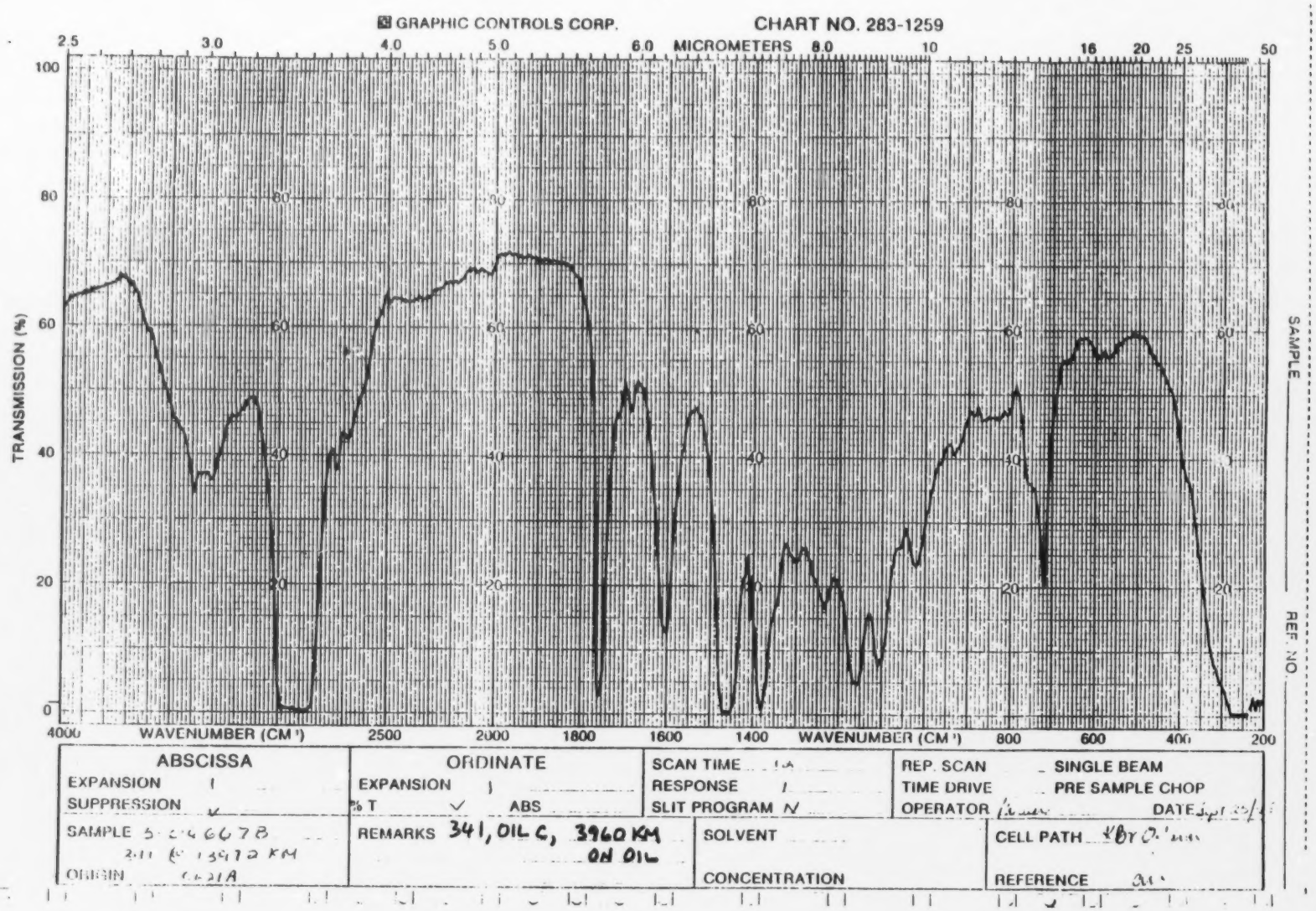
SOLVENT
CELL PATH KBr
CONCENTRATION
REFERENCE
ORIGIN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100 80 60 40 20 0
TRANSMISSION (%)
4000 WAVENUMBER (CM⁻¹) 2500 2000 1800 1600 1400 WAVENUMBER (CM⁻¹) 800 600 400 200
SAMPLE
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ABSCISSA
EXPANSION 1
SUPPRESSION
ORDINATE
EXPANSION 1
% T ✓ ABS
SCAN TIME
RESPONSE 1
SLIT PROGRAM N
REP. SCAN SINGLE BEAM
TIME DRIVE PRE SAMPLE CHOP
OPERATOR DATE
SAMPLE 5 C 46678
2.11 & 13972 KM
ORIGIN C-21A
REMARKS 341, OIL C, 3960 KM
ON OIL
SOLVENT
CONCENTRATION
CELL PATH
REFERENCE

APPENDIX D/ USED-OIL ANALYSIS RESULT INTERPRETATION

APPENDIX D/ USED-OIL ANALYSIS RESULT INTERPRETATION

Tests	Results "Warning Limits"	"Median"	"90%ile"	"Typical"	"Range"	Components
TBN	50% drop	-	-	-		
Viscosity @100°C	25% drop	-	-	-		
Pentane Insol., % by mass	>1.5	-	-	-		
Al, ppm	>40	19	15	-	15-40	Pistons
Cr	>40	6.4	-	-	5-30	Rings
Cu	>40	22	35	-	5-40	Bearings, Bushings
Fe	>100	47	75	-	40-200	Cylinders
Pb	>40	-	-	-	-	Bearings
Si	>20	18	17	20	5-25	Dirt
Source	1	2	3	4	5	

- All above data refer to used-oil condition at drain.

Sources:
1/ "Testing Used Engine Oils," Chevron Research Co., 1983
2/ SAE Paper 77-642 (on diesel engines)
3/ SAE Paper 73-745 (on diesel engines)
4/ Fuels and Lubes Magazine, Sept./Oct., 1980
5/ SAE Paper 77-85 (on automobile engines)

APPENDIX E/ A SURVEY OF GASOLINE ENGINE FIELD TESTS

APPENDIX E/ A SURVEY OF GASOLINE ENGINE FIELD TESTS

To qualify an oil for use in 1980 or later gasoline engines (produced in North America), the American Petroleum Institute (API) requirements for an "SF" quality oil must be met.

There are four basic standardized tests with specific requirements that must be met by a motor oil prior to the use of the term "SF" quality:

1/ The Sequence II-D Test evaluates the rusting and corrosion characteristics of motor oils. This test method is designed to relate particularly to short-trip service under winter conditions in the upper midwest United States.

2/ The Sequence III-D test evaluates the high-temperature oil-thickening characteristics, sludge and varnish deposits, as well as engine wear of motor oils. This test method is designed to relate to high-speed highway operation under summer conditions in the south and southwest United States.

3/ The Sequence V-D test evaluates the sludge and varnish deposits of motor oils. This test method is designed to relate to a combination of low-speed, low-temperature, stop-and-go city driving and moderate highway operation in the northeast United States.

4/ The Labeco L-38 test evaluates the stability, corrosive tendency, and viscosity change of motor oils at high temperatures.

In general, any field tests of motor oils relate directly to one of these four engine tests. For example, a field test under short-trip, cold-engine conditions would relate to the Sequence II-D performance. This indicates that only rusting or corrosion tendencies would be rated, not engine wear.

The tests were developed as these areas of performance are most important to ensure acceptable gasoline engine durability. The development of the gasoline engine and its lubricant have been closely intertwined: as engines changed, the lubricant and its quality level changed accordingly.

The possible widespread use of fuel-methancl in the future has only recently been seriously considered. Initially, as the engines are very similar for gasoline and fuel-methanol, no problems with engine lubrication were envisioned. However, various researchers [3-7] found that

engine durability was a problem, especially under cold engine, short-trip conditions.

The Ford/Shell program, as detailed in this report, addressed the concern that engine wear under these conditions could be critical. As such, no direct comparisons with gasoline-fuelled engines can be made. However, some indications of acceptable engine durability can be inferred from gasoline field tests under various conditions.

Various researchers' data are summarized and the expected engine durability parameters estimated at 4000 km, the distance accumulated in Phase 3, allowing comparison between the results given in this report and results for gasoline.

E.1/ Reference : Pless, L.G., "A Study of Lengthened Engine Oil-Change Intervals," SAE Paper 740139.

No. of Vehicles : 109

Oil Type : 9 oils, SC, SD, SE quality

Oil Viscosity Grade: 20, 30, 40

Oil Drain Period : 16 100 to 41 800 km

Total Distance Travelled : 37 000 to 257 500 km

Parameters Measured: Cam & lifter, ring gap

Results :

To Final Distance Accumulation (257 500 km)	4000 km Equivalent
Cam & Lifter Wear:	
17 cars; 95 to 155 µm (S. Florida Taxis, 1971)	1.5 to 2.4 µm
13 cars; 65 to 195 µm (S. Florida Taxis, 1972)	1.0 to 3.0 µm
11 cars; 70 to 90 µm (C. Indiana Taxis 1971)	1.1 to 1.4 µm
Ring Gap Growth	
17 cars; Top: 350 to 650 µm	5.4 to 10.1 µm
2nd: 325 to 575 µm (S. Florida Taxis	5.0 to 8.9 µm
18 cars; Top: 250 to 525 µm	3.9 to 8.2 µm
2nd: 325 to 450 µm (S. Florida Taxis)	5.0 to 7.0 µm
11 cars; Top: 175 to 200 µm	2.7 to 3.1 µm
2nd: 325 to 400 µm (C. Indiana Taxis)	5.0 to 6.2 µm

E.2/ Reference : Nolf, A.R., and Schlobohm, R.T., "Anti-Rust Performance of Ash and Ashless Crankcase Oils in Short Trip Service," SAE Paper 740140.

No. of Vehicles : 11

Oil Type : 10 types, large range, 0 to 1.0% by mass ash

Oil Viscosity Grade: 5W40, 10W30, 10W50

Oil Drain Period : Test length

Total Distance Travelled : 2200 km

Parameters Measured: Lifter rust

Results :

To Final Distance Accumulation		4000 km Equivalent
Average Lifter Rust:	9.0 to 9.5 (10 = Clean) @ 800 km	5.0 to 7.5
	7.7 to 9.4 (10 = Clean) @ 1600 km	4.3 to 8.5
	5.1 to 9.4 (10 = Clean) @ 2200 km	1.1 to 8.9

Comments:
- Aunt Minnie test for rust performance.
- Very severe test.
- Rust performance exponentially decreases with time or distance travelled.
- All normal quality oils had ratings >8.8 @ 2200 km. >7.8

E.3/ **Reference** : Rodgers, J.J., and Kabel, R.H., "Vehicle Evaluation of Synthetic and Conventional Oils," SAE Paper 750827.

No. of Vehicles : 5

Oil Type : 3 synthetic, 1 conventional

Oil Viscosity Grade: 5W20, 10W40

Oil Drain Period : 12 000 to 32 000 km

Total Distance Travelled : 64 000 km

Parameters Measured: Cam wear, sludge, varnish, and rust

Results :

	To Final Distance Accumulation (64 000 km)	**4000 km Equivalent**
Cam Wear:	2 to 12 μm avg.	0.125 to 0.75 μm
Sludge :	9.6 to 9.8 avg. (10 = Clean)	9.9+
Varnish :	9.7 to 9.8 avg. (10 = Clean)	9.9+
Rust :	8.5 to 9.1 avg. (10 = Clean)	9.9+

Comments: Mild test, minimal wear.
No advantage of synthetics over conventional oils apparent.

E.4/ Reference : Pless, L.G., and Rodgers, J.J., "Cam and Lifter Wear as Affected by Engine Oil ZDP Concentration and Type," SAE Paper 77087.

No. of Vehicles : 127

Oil Type : SE/CC, SE/CD

Oil Viscosity Grade: 10W40, 30, 20W20

Oil Drain Period : 4800 to 41 800 km

Total Distance Travelled : 37 000 to 259 100 km

Parameters Measured: Cam and lifter wear

Results :

To Final Distance Accumulation (per 10 000 km)	**4000 km Equivalent**
Cam & Lifter Wear:	
15 cars; 4.6 to 10.7 μm Indianapolis Taxis	1.8 to 4.3 μm
19 cars; 1.3 to 4.6 μm Lansing Police Cars	0.5 to 1.8 μm
17 cars; 11.9 to 20.1 μm Phoenix and Los Angeles Taxis	4.8 to 8.0 μm
5 cars; 10.1 μm San Diego Taxis	4.0 μm
2 cars; 3.3 μm California State Cars	1.3 μm
6 cars; 2.2 to 4.4 μm GMR General Transportation Cars	0.9 to 1.8 μm
8 cars; 4.7 to 13.1 μm Ft. Lauderdale Taxis	1.9 to 5.2 μm

E.5/ Reference : Bardy, D.C., et al, "A 2.3 L Engine Deposit and Wear Test - An ASTM Task Force Progress Report," SAE Paper 780260.

No. of Vehicles : 61

Oil Type : Various

Oil Viscosity Grade: Various

Oil Drain Period : 9700 to 32 200 km

Total Distance Travelled : 77 200 to 160 900 km

Parameters Measured: Sludge, varnish, cam wear, cylinder bore wear bearing weight loss (not done on all cars)

Results :

To Final Distance Accumulation			4000 km Equivalent
Sludge	:	5.8 to 9.5 (10 = Clean)	9.6+
Varnish	:	3.6 to 7.8 (10 = Clean)	8.4+
Cam Wear	:	31 to 53 µm	<13 µm
Lifter Wear	:	36 to 64 µm	<15 µm
Cyl. Bore Wear	:	51 to 86 µm	<8 µm
Brng. Wt. Loss	:	73 to 184 mg	<15.3 mg

E.6/ Reference : Miller, M.S., et al, "A Field Correlation of the Sequence V-D Engine Test," SAE Paper 820084.

No. of Vehicles : 5

Oil Type : SF, SE/DC

Oil Viscosity Grade: 5W30, 15W40

Oil Drain Period : 12 000 and 24 000 km

Total Distance Travelled : 72 000 km

Parameters Measured: Sludge, varnish, cam wear, rod bearing wt. loss

Results :

To Final Distance Accumulation			4000 km Equivalent
Sludge	:	9.6 to 9.7 @72 000 km (10 = Clean)	9.9+
Varnish	:	8.5 to 9.4 @72 000 km (10 = Clean)	9.9+
Average Cam Wear	:	5 to 10 µm for SF oils @72 000 km	
		46 µm for SE/CD oil @ 53 700 km	0.25 to 0.5 µm 3.4 µm
Rod Bearing Wt. Loss:	:	32.4 to 42.9 mg for SF oils @ 72 000 km	1.8 to 2.4 mg
		64.7 mg for SE/CD oil @53 700 km	4.8 mg

E.7/ Reference : Flathmann, D.E., et al, "Wear Performance of an SAE 0W30 Partial-Synthetic Motor Oil Under High Speed Driving Condition," SAE Paper 821196.

No. of Vehicles : 6

Oil Type : SF Quality

Oil Viscosity Grade: 0W30, 10W30

Oil Drain Period : 12 000 km

Total Distance Travelled : 80 000 km

Parameters Measured: Rod bearings, main bearings, piston rings, cyl. bore, cam wear, sludge, varnish, used-oil analysis

Results :

	To Final Distance Accumulation (80 000 km)	4000 km Equivalent
Rod Brng. Wt. Loss	42.6 mg	2.2 mg
Main Brng Wt. Loss	48.9 mg	2.5 mg
Piston Ring Wt. Loss	Top: 41.9 mg	2.1 mg
	2nd: 25.2 mg	1.3 mg
Cyl. Bore Wear	4.3 μm	0.2 μm
Cam Wear	12 μm	0.6 μm
Sludge	9.8 (10 = Clean)	9.9+
Varnish	8.7 (10 = Clean)	9.9+
Used-Oil Analysis (12 000 km drain intervals)	Al 18, 3, 9 (10 avg.) ppm	3.3 ppm
	Cr 2, 1, 1 (1 avg.) ppm	<1.0 ppm
	Cu 3, 33, 3 (13 avg.) ppm	4.3 ppm
	Fe 37, 15, 50 (34 avg.) ppm	11.3 ppm
	Si 23, 7, 7 (12 avg.) ppm	4.0 ppm
	Pb 39, 45, 42 (42 avg.) ppm	14.0 ppm

E.8/ Reference : Harris, S.W., and Zahalka, T.L., "A Field Test Study of Camshaft Wear in a 2.3 L OHC Engine and Its Correlation to the Sequence V-D Test," SAE Paper 831758.

No. of Vehicles : 20

Oil Type : 5 types SF/CC, SF/CD Quality

Oil Viscosity Grade: 15W40 and 10W30

Oil Drain Period : 24 000 km

Total Distance Travelled : 48 000 to 80 000 km

Parameters Measured: Camshaft wear

Results :

	To Final Distance Accumulation	**4000 km Equivalent**
Cam Wear	13 to 20 μm @ 16 000 km	2.5 to 5 μm
	15 to 25 μm @ 24 000 km	2.5 to 5 μm
	18 to 38 μm @ 48 000 km	2.5 μm
Follower Wear	<9 mg wt. loss @ 16 000 km	<2.3 mg
	<17 mg wt. loss @ 24 000 km	<2.8 mg
Iron Level	163 to 227 ppm @ 24 000 km (1st drain)	27 to 38 ppm
	145 to 267 ppm @ 48 000 km (2nd drain)	24 to 45 ppm

Comments :
- Cam wear is an inverse exponential relation.
- Long drain periods accentuate wear problems.

E.9/ Reference : Smolenski, D.J., and Kabel, R.H., "Effect of Engine Oil Zinc Dithiophosphate (ZDP) Additive Type on Cam and Lifter Wear in Taxi Service," SAE Paper 831760.

No. of Vehicles : 56

Oil Type : 9 types, 3SF, 6 < SF Quality

Oil Viscosity Grade: 10W30, 20W30

Oil Drain Period : 12 000 km ± 1200 km

Total Distance Travelled : 108 000 to 165 000 km

Parameters Measured: Sludge, varnish, cam and lifter wear

Results :

To Final Distance Accumulation (161 000 km)			**4000 km Equivalent**
Sludge	:	9.3 to 9.6, (10 = Clean)	9.9+
Varnish	:	6.0 to 7.3, (10 = Clean)	9.8+
Cam and Lifter Wear:			
Average	:	86 to 246 μm	2.1 to 6.1 μm
Maximum	:	445 to 1412 μm	11.1 to 35.1 μm
Comments	:	Long drains in severe service Avg. cam + lifter wear <150 μm Appears acceptable	3.7 μm

E.10/ Comparison of Literature Wear Results with Methanol Performance

Parameter	Expected Results with Gasoline @ 4000 km	Phase 3 Results
Cam & Lifter Wear	5 μm	
Cam Wear	13 μm	<50 μm
	<5 μm more typical max.	
Sludge (10 = Clean)	9.6+	9.7+
Varnish (10 = Clean)	8.4+ min.	8.9+
	9.8+ more typical min.	
Top Ring Wt. Loss	2.1 mg	<115 mg
Top Ring Gap Growth	<10 μm	<100 μm
Cylinder Bore Wear	<7.5 μm	<10 μm
	<0.25 more typical max.	
Bearing Wt. Loss	<15.3 mg max.	<57 mg max.
	<4.8 mg more typical max.	<15 mg typ.
Used-Oil Fe Level	<45 ppm	<145 ppm

APPENDIX F/ EXHAUST EMISSION AND FUEL CONSUMPTION DATA

APPENDIX F/ EXHAUST EMISSION AND FUEL CONSUMPTION DATA

F.1/ Car 339

1975 Constant Volume System (CVS) & Highway Fuel Economy Test (HWFET) Emission Test Results

Car year, make, model, displ., carb.	= Ford Escort MeOH
Car no. or lic. no. (catalyst?)	= 339
Description of test	= Emissions, 25°C
Date of test + other info	=
Dynamometer run number(s)	=
Dyno windage setting	= 0.0
Dyno inertia setting	= 0.125
Fuel density (g/mL)	= 0.7887
Fuel-percent carbon	= 42.73
Odometer reading (km)	= 30 000.0
Vehicle inertia weight (kg)	= 1077.3
Dyno hp (indicated) at 80 km/h	= 6.0
Actual urban distance (km)	= 17.89
Actual highway distance (km)	= 16.47
Ambient barometric pressure (kPa)	= 100.95
Specific humidity (kg moisture/kg dry air)	= 0.0134
Relative humidity percent	= 66.4

Mass Emissions (g/km)

Transient Cold	Stabilized Cold	Transient Hot
HC = 1.10	HC = 0.47	HC = 0.26
CO = 15.23	CO = 0.79	CO = 7.46
NO_x = 0.97	NO_x = 0.37	NO_x = 0.45
CO_2 = 184.39	CO_2 = 223.31	CO_2 = 170.54

Test Summary (Weighted and Corrected, g/km)

City	HC = 0.55	CO = 5.58	NO_x = 0.51	CO_2 = 200.9
Highway	HC = 0.06	CO = 0.12	NO_x = 0.36	CO_2 = 128.2

Fuel Consumption Data

	Fuel Consumed, mL	Actual Dist. Travelled, km
Trans. cold =	979.71	5.78
Stab. cold =	1089.64	6.33
Trans. hot =	849.63	5.78
Highway =	1623.56	16.47

Fuel Consumption

CVS C/H

	Carbon Balance (L/100 km)	Direct Measure (L/100 km)	Difference (%)
Trans. cold	= 17.16	16.95	-1.24
Stab. cold	= 18.31	17.21	-6.38
Trans. hot	= 14.83	14.70	-0.90
Weighted CVS	= 17.13	16.48	-3.95
Unweighted	= 16.81	16.32	-3.05
Highway	= 10.41	9.86	-5.64
Combined rating	= 14.11	13.50	-4.51

Steady States

L/100 km at 60 km/h = 7.71
L/100 km at 100 km/h = 10.79

E.2/ Car 340

1975 CVS & HWFET Emission Test Results

Car year, make, model, displ., carb.	= Ford Escort MeOH
Car no. or lic. no. (catalyst?)	= 340
Description of test	= emissions, 25°C
Date of test + other info	= 85-07-12
Dynamometer run number(s)	= 6796-7-8-9
Dyno windage setting	= 0.0
Dyno inertia setting	= 0.125
Fuel density (g/mL)	= 0.7887
Fuel-percent carbon	= 42.73
Odometer reading (km)	= 30 000.0
Vehicle inertia weight (kg)	= 1077.3
Dyno hp (indicated) at 80 km/h	= 6.0
Actual urban distance (km)	= 17.88
Actual highway distance (km)	= 16.41
Ambient barometric pressure (kPa)	= 100.71
Specific humidity (kg moisture/kg dry air)	= 0.0134
Relative humidity percent	= 66.5

Mass Emissions (g/km)

Transient Cold	Stabilized Cold	Transient Hot
HC = 0.91	HC = 0.23	HC = 0.22
CO = 13.22	CO = 0.68	CO = 7.09
NO_x = 0.91	NO_x = 0.28	NO_x = 0.40
CO_2 = 186.58	CO_2 = 215.64	CO_2 = 170.35

Test Summary (Weighted and Corrected g/km)

City	HC = 0.37	CO = 5.01	NO_x = 0.44	CO_2 = 197.3
Highway	HC = 0.05	CO = 0.19	NO_x = 0.40	CO_2 = 125.2

Fuel Consumption Data

	Fuel Consumed, mL	Actual Dist. Travelled, km
Trans. cold =	957.02	5.79
Stab. cold =	1053.38	6.32
Trans. hot =	824.52	5.77
Highway =	1573.22	16.41

Fuel Consumption

CVS C/H

	Carbon Balance (L/100 km)	Direct Measure (L/100 km)	Difference (%)
Trans. cold	= 17.03	16.53	-3.03
Stab. cold	= 17.61	16.67	-5.68
Trans. hot	= 14.76	14.29	-3.27
Weighted CVS	= 16.72	15.99	-4.52
Unweighted	= 16.50	15.86	-4.07
Highway	= 10.18	9.59	-6.20
Combined rating	= 13.78	13.11	-5.07

Steady States

L/100 km at 60 km/h = 7.84
L/100 km at 100 km/h = 10.48